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The Symposium was devoted to the renovation and reuse of wastewaters from municipal, industrial, and agricultural sources. The proceedings are divided into eleven chapters addressing key concerns that must be satisfied prior to successful implementation of water reuse. Economics, regulatory and legal constraints, health effects, water quality needs, planning, and engineering, among other factors, are covered for wastewater sources and water users. The proceedings demonstrate that significant global interest exists in wastewater reuse, that recycling concepts are being applied to a broad range of functions, that application of water reuse may be highly situation-dependent, and that reuse applications are important solutions for the conservation of water. Volume 1 focuses on: (1) needs and funding alternatives for water reuse in the future; (2) municipal wastewater reclamation and reuse and water supply augmentation; (3) water reuse around the world; and (4) industrial recycling and reuse.

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Symposium Administrator
American Water Works Association (AWWA)
Research Foundation
Denver, Colorado

AWWA Research Foundation
6666 West Quincy Avenue
Denver, Colorado USA 80235
Phone: (303) 794-7711

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FOREWORD

Water reuse has been practiced in one form or another since early civilization, but planned direct water reuse has only recently been studied and practiced widely in the water use community. Today there is a greater interest in water reuse than ever before. This Symposium was designed to provide a forum for that interest.

The Symposium was the second week-long meeting dedicated to the renovation and reuse of wastewater to satisfy man's ever-increasing demand for fresh water. The Symposium addressed new approaches, innovative technologies, recent experiences and practical applications of water reclamation.

These proceedings have been divided into eleven chapters addressing key concerns that must be satisfied prior to successful implementation of water reuse. Economics, regulatory and legal constraints, health effects, water quality needs, planning, and engineering, among other factors, are covered for municipal, industrial and agricultural wastewater sources and water users.

The Symposium consisted of fourteen technical sessions and three poster sessions with a total of 165 presentations. These proceedings consist of 150 of those papers submitted by the authors. In addition, 10 papers by authors who had been invited to attend but were not present have also been published in these three volumes.

The material presented herein is published as submitted by the authors. No attempt was made by the Symposium co-sponsors to edit, reformat or alter the material except where necessary for production requirements or where obvious errors were detected. Any statements or views here presented are totally those of the authors, and are neither condoned nor disputed by the Symposium co-sponsors. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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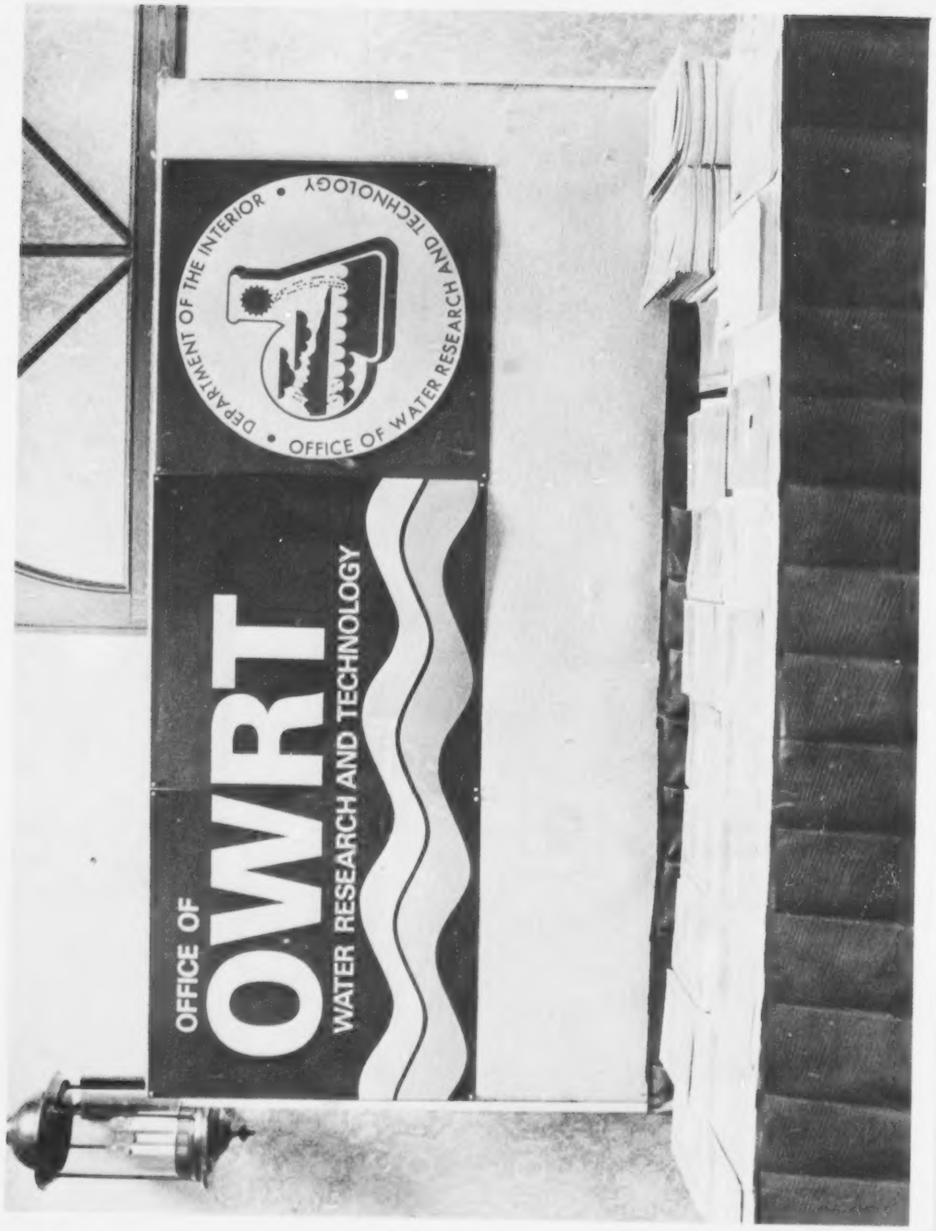
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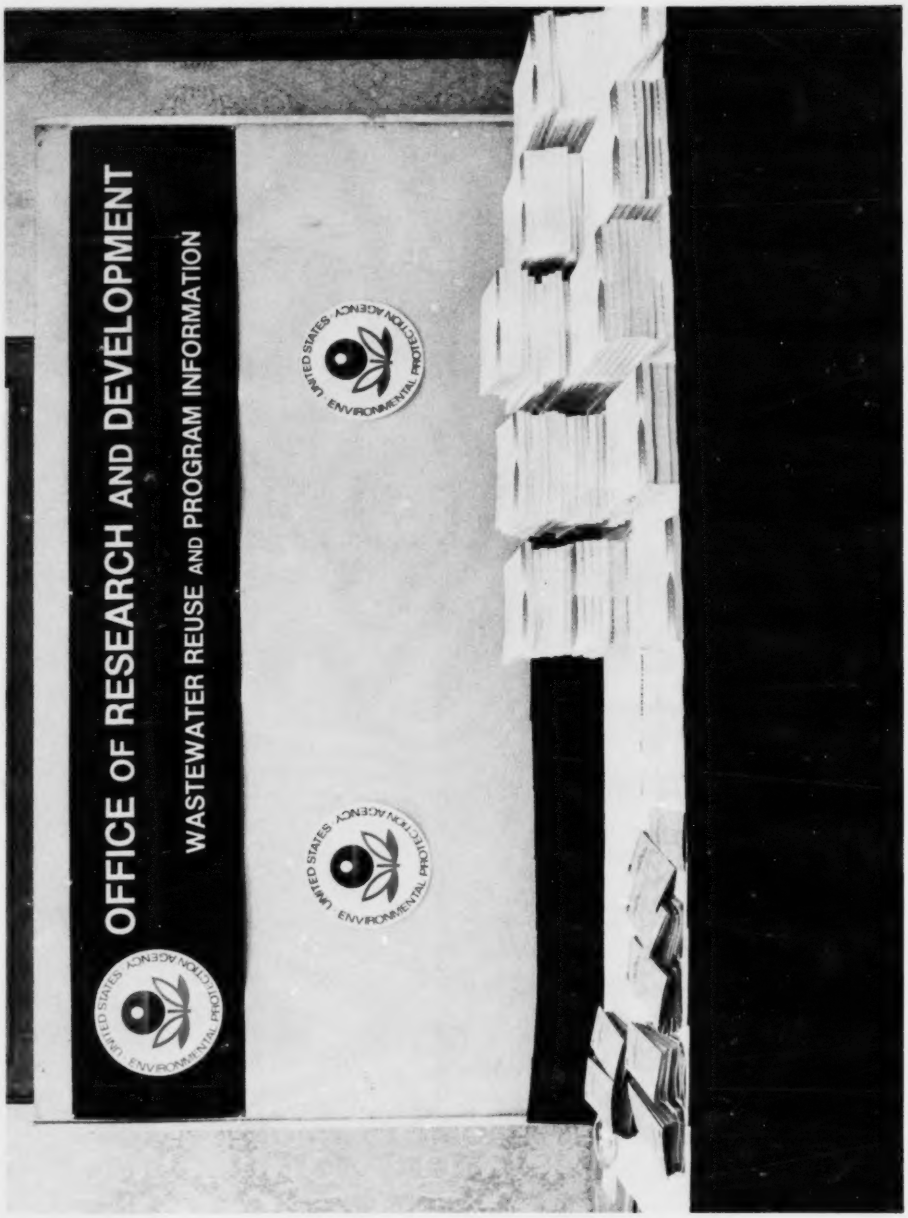
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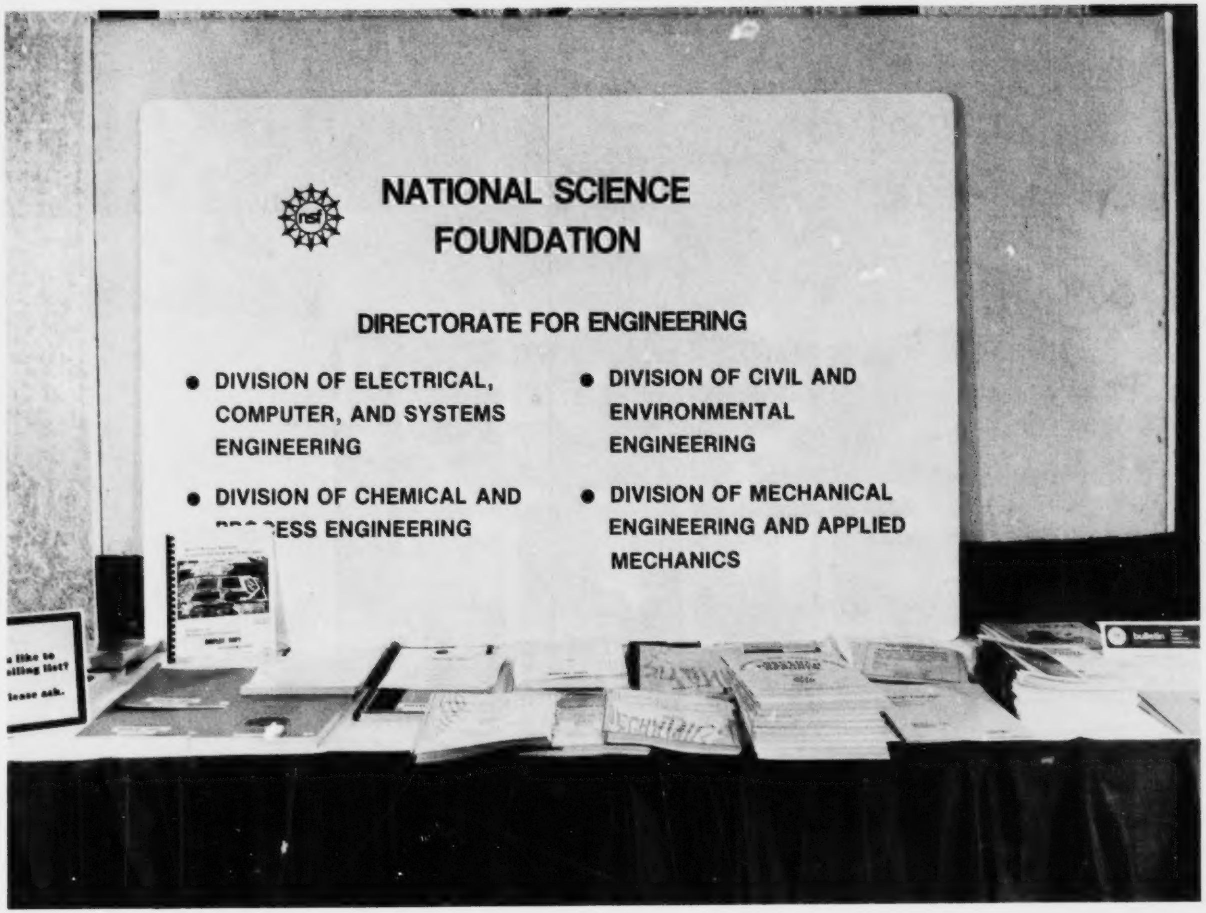
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WATER REUSE
SYMPOSIUM II

WATER REUSE IN THE FUTURE:

NEEDS AND FUNDING ALTERNATIVES

PB82-223090

"WATER REUSE IN THE FUTURE"

Kenneth J. Miller
President
American Water Works Association
Vice President and Director of Water Engineering
CH2M HILL Consulting Engineers
Box 22508
Denver, Colorado 80222

I. Introduction

I am very pleased to be asked to be the "Theme Speaker" at this second water-reuse symposium. I commend the eight cosponsors and the commitment of their staffs to organize and coordinate the arrangements for the success of this symposium. The excellent registration and the number of participants from all sectors of our industry and government attest to their success.

The theme of this year's symposium is "Water Reuse In the Future." The program for the next 4 days certainly relates to that theme. The outline of session themes and the subjects of the technical papers on water-reuse activity in the United States and around the world is a brief synopsis of our progress in water recycling. I look forward to attending the sessions and participating during the next 4 days.

This morning, I have broken my presentation into an overview of the history of water reuse, current water-reuse practices, and my perception of water reuse in the future. Along the way, I will take the liberty of addressing several issues which are interrelated to water reuse, such as:

- The role of government in future water-reuse programs.
- The need for health-effects research.
- Public participation.
- AWT and water treatment spinoffs.
- Reuse incentives and motivation.
- The role of government in water-reuse research and demonstration facilities.

II. The History of Water Reuse

Planned and unplanned water reuse and direct and indirect water reuse are not new terms developed to describe water reuse in the 21st century. They can be applied equally to water-reuse practices before the birth of Christ. Records indicate planned wastewater reuse in Rome and Greece for agriculture prior to the first century, and in England, Germany, and the United States in the 18th century. I am sure that water and wastewater journals throughout the world have recorded instances of direct and indirect reuse of waste effluents in the last 100 years

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which would fill an engineering textbook. The point is that water reuse has been with us for over 2,000 years. It will continue to increase in popularity as a basic water resource with or without our planning efforts. We are gathered here to discuss water reuse as a planned, well-reviewed option for industry, agriculture, and municipalities.

Industrialization, increased standard of living, and the population increases of the last century have stimulated innovative approaches to water recycling; most of these cases were not reported in the literature prior to 1950. Before this period, wastewater, sewage, sludge handling, solid waste handling, and recycling were subjects which each county handled or mishandled without a great deal of public interest. Cases like those of Chanute, Kansas, and Windhock, South Africa, startled the water supply community when direct potable reuse was proposed.

Indirectly, technology of water reuse has been negatively impacted by our reticence to accept existing reclamation practices of industries and the communities in which we reside. The best example that I can cite which supports this claim is the potable water supply industry in the United States. There are very few surface water supplies in the United States which do not receive wastewater discharges from upstream municipalities and industries. In-stream purification, i.e., simple dilution, was not supportable by scientific evidence. While early settlers of this country often established their homes next to good-quality water supplies, by the early 1950s nearly all surface water and some ground water showed evidence of man's industrial and municipal wastes.

It is interesting to note that one popular beer manufacturer today refers to its product as an "upland high-country" beer. In my home state, several national breweries are looking for high-elevation land served by a "pristine" water source. While I am sure that this sells a lot of beer, it also reflects a concensus attitude about water reuse and potable water supply.

Notwithstanding this apparent sentiment of the consuming public, indirect and direct reuse has been contributing to our recreational and agricultural water, aquifer recharge, and potable water supply for more years than we care to acknowledge.

My point in reviewing this very brief history of water reuse is to focus for a few minutes on the past. Water reuse began out of necessity, necessity brought about by expanding industries, ever-increasing populations, the need for larger volumes of water to support increasing agricultural needs. As mankind approaches the 21st century with a projected world population nearly doubling by the year 2000, it would seem very realistic to project that, without significant change, our existing water resources will be taxed beyond our current abilities to satisfy demand.

It is not a question of committing higher quality water for domestic use, a principle upon which all of us would agree, but one of recycling to meet new demands for maintaining and improving the standard of living of the earth's inhabitants.

Projects like the Dan Region in Israel and the Orange County Factory 21, have made major contributions to the technology of ground water recharge and reuse. Hopefully, projects like Denver Reuse Demonstration Plant and the Potomac Estuary Plant

will contribute to our knowledge of direct planned potable reuse.

In my review of past reuse practices, the City of St. Petersburg, Florida, is an outstanding example of planned wastewater reuse via a dual-distribution system. The City is currently treating 38 mgd of municipal wastewater and irrigating 1,500 acres of land. Year 2000 figures suggest daily flows of 62 million gallons of wastewater capable of treating nearly 7,000 acres. When complete, the system will have 80 miles of distribution lines and 250 miles of irrigation lines, a most interesting and creative undertaking. While reports regarding the more innovative municipal reuse practices of the past 30 years have been published, reports of water reuse by industries and agriculture have received less exposure. With the advent of recent environmental regulations, i.e., the NPDES permits and other requirements of the Clean Water Act, industrial reuse has grown in popularity. I am pleased to see two sessions of this year's symposium directly related to industrial recycling and reuse.

III. Current Practices

It is not my intention to sum up all of the past issues of Water Reuse which relate to current practices, and which were written by R. O. Heaton and other AWWA Research Foundation staff members. However, I would like to highlight some current practices and explore the motivation supporting these efforts.

Water reuse for agriculture is finding increasing interest, even in areas thought to be water-rich. During a recent trip to Puerto Rico, I was pleased to observe the practice of wastewater reuse by the sugar cane industry. I note that Mr. Rios and Mr. Lao-Calon are scheduled on the program this afternoon to speak on the development of a wastewater reclamation model in Puerto Rico. In this case, I believe their motivation is typical when evaluating agricultural reuse; it is augmenting and extending existing supplies and irrigating new land for crop production.

It is interesting to note the number of states which have promulgated regulations dealing with water quality standards relating to agricultural reuse. The latest proposed regulations come from the Arizona Department of Health. These effluent quality standards for agricultural uses almost always relate to the intended use of the product, and whether the product undergoes a pathogen-destroying process. In any event, we are seeing new crops and new products being irrigated with wastewaters. The conventional applications golf courses, parks, freeways, cemeteries, and playgrounds are giving way to fodder, and seed crops fiber. Food crops such as orchards, vineyards, and products which undergo processing to destroy pathogenic bacteria, are finding increasing use for reclaimed water.

A most interesting case study developing in the immediate future involves the State of Arizona and the Central Arizona Project water. Arizona has the climate, the available land, and will shortly have increased volumes of reclaimed wastewater available for agricultural reuse. The issue of Indian water rights, another case of agricultural use, has already surfaced in the Arizona water courts.

Recreational reuse currently being practiced seems to be limited to application to parks, golf courses, and football and baseball fields. However, each country can cite a reservoir which is predominately filled with reclaimed wastewater and used for nonbody-contact sports. Since the peaks between supply and demand must be leveled, we are seeing new storage impoundments which will support recreational use. Bacterial/microbiological standards have been developed for recreational use; in some instances, the uses include body-contact sports.

Industrial water-reuse applications are probably the fastest growing in the water reclamation field, and the ones which have received the least publicity. Water reclamation in many industries has been practiced because of the sheer economics of resource recovery. The recent Clean Water Act regulations have provided the cost incentive for second-generation industrial recycling to meet discharge limits. Many of these reclamation programs pay for the cost of cleanup by recovering essential byproducts. This symposium lists 19 industrial recycling and reuse papers, a fact of which further illustrates the interest in and importance of recycling.

Domestic reuse of reclaimed wastewater continues to be very site-specific and probably represents less than 5 percent of the number of reuse projects by the year 2000. Aquifer recharge similar to the Dan Region and Factory 21 will continue to be a viable option to direct potable reuse. The Potomac Estuary Plant in Washington, D.C., and the Denver Demonstration Facility under construction will make significant contributions to the potable reuse alternative. Both facilities deal with the operation and demonstration of state-of-the-art technology. The Denver reuse plant is also committed to a very extensive health-effects research program.

I will stop here for a moment to speak about the often-misunderstood motivation of the Denver Water Department to spend nearly $25 million for the evaluation of potable reuse. The Denver metropolitan area population is currently 1.5 million; regional planning estimates conservatively the year 2000 population at 2.3 to 3.0 million. Denver's present water supply is capable of delivering 365,000 acre-feet/year, but by the year 2000, it estimates a need for 700,000 acre-feet/year. There is simply not 335,000 acre-feet of water available under the appropriation doctrine, which must also compete with synthetic fuels, coal, agriculture, and energy for the remaining water in Colorado. If the needs of the growing Denver metropolitan area are to be met, potable reuse must be thoroughly evaluated.

In Denver's case, projected costs of potable reuse will be competitive with new resource development by the year 1990. Since only transbasin water can be recycled, Denver must develop existing water rights and be ready to implement some form of potable reuse by the turn of the century. To wait until the year 2000 to evaluate the water resource options available to the City would be short sighted planning by the Denver Water Department.

IV. Water-Reuse Practices in the Future

In 1776, this country did not have a water reuse or water resource problem. It was blessed with an abundance of high-quality water to meet nearly all of its domestic, industrial, and agricultural needs, and the country had no reason to develop a long-range water management plan. I am sure we have all recognized that the major factor influencing water is people. Larger populations, and a higher standard of living require more water to satisfy domestic and industrial needs. Unfortunately, growth and population increases have generally been associated with water- quality deterioration. The quality of many of the earth's surface supplies will continue to show deterioration until at some point, planned reuse and its associated treatment process will offer a higher-quality product than conventional treatment. In the United States, approximately one-half of our 220 million people are supplied with water from surface supplies and one-half from ground water sources. It was presumed that our ground waters would provide excellent "last ditch" fallback for some communities while we worked at returning our surface supplies to "swimmable/fishable" quality.

After nearly 10 years, we are learning that our surface supplies, while improving, will never be swimmable/fishable, if indeed they ever were, and that our ground waters are showing evidence of man's encroachment and the byproducts of his industrial renaissance. The need for ever-improving AWT processes and recycling technology will continue to grow worldwide as the population increases and the standard of living of the third-world developing nations hopefully begins to improve. The key to our success in dealing with man's new water-resource problems lies in our ability to extend and augment existing supplies through various reclamation processes. It would seem that success in water-reuse technology is dependent upon our ability to communicate and apply the advances that are achieved.

I am sure that most of you assembled here today are aware that the decade of the 1980s has been named the "World Water Decade" by the United Nations. Figures published by the United Nations and the World Health Association indicate that three-quarters of the earth's inhabitants drink something less than potable-quality water. These same agencies report that approximately 15 million deaths occur each year to children before reaching the age of 5 from waterborne causes. The simple technology of water purification and disinfection has not been communicated or applied to the third-world countries.

The task of applying current state-of-the-art in water reuse will tax the ingenuity of all sectors of our society, not just the water-supply community. Symposiums like this are intended to contribute to the needs of the scientific and technical communities in the ever-changing field of water reclamation.

I believe we have learned that future water reuse will not be limited by our ability to successfully treat wastewater, but by the costs associated with the construction and operation of the treatment process selected. In the not-to-distant future, water will be processed or recycled to a desired quality level. This will require water quality standards which will relate not only to quality, but to the intended use. There could conceivably be five or six water quality standards for agricultural use dependent on the crop and its intended use. I believe industrial reuse standards will also be promulgated which directly relate to industries needs. Notwithstanding, governments will primarily be concerned with industry's effluent discharge standards. The primary goal will continue to be to remove the contaminte at its source, not after discharging to a receiving stream or river.

The major role of government in future water reuse programs should be to coordinate research and demonstration projects and to promulgate controlling rules and regulations. At the present time, over ten government agencies have some interest in water reuse and recycling. I would recommend, for the sake of efficiency and sound management, that one agency be designated to coordinate and manage all reuse research and demonstration projects. In my opinion, we do not need to have research minicenters in each of the 50 states. The problems are not that dissimilar and should not have to be solved independently.

Another role of the national and state government agencies coordinating water reuse would be to conduct an extensive health effects program. Their goal would be to develop permissible levels of organics, inorganics, trace metals and microbiological agents in each of the proposed reuse applications, i.e., the various qualities of ground water recharge effluents, agricultural reuse qualities, and domestic reuse. Maximum contaminate levels (MCLs) should be established now which will relate to existing and known health effect data. These levels should be updated yearly as new health effects information is obtained.

I would be remiss if I did not emphasize the need for public participation at each step of the reuse program, which would also include industrial reuse. The public should not be expected to understand and support reuse research and demonstration projects, which they do not understand and when they are not part of the team effort from the beginning of the reclamation program. Since water and wastewater effluents are perceived to be a significant part of our natural resources, they will continue to receive greater scrutiny by the public. Their role can be one of a supporting partner or a major antagonist. The difference seems to be involvement by all parts of the public--local and national.

C. C. Johnson in his summary of last years reuse symposium on Protocal Development: Criteria and Standards For Potable Reuse, entitled his comments "Water Reuse: An Unfinished Agenda." I agree with C. C.; the national water reuse program is unfinished.

I strongly recommend that a national water reuse management program be implemented, and that the following points be considered:

1. The designation of one government agency to coordinate all water reuse research and demonstration activities, including conservation, public participation and education.

2. That the present EPA policy statement on water reclamation and reuse be updated to reflect the program development in the last 7 years.

3. That the updated policy statement become a part of the administration's announced program to develop a single national water policy.

4. That health-effects research be expanded to relate to the present and future reuse practices.

5. That we begin now to develop a cooperative effort between industry; municipalties; agricultural, local, state, and national government; and the general public to develop this country's water resource potential through planned water reclamation and recycling.

I look forward to attending the symposium and reading the proceedings on those papers which I miss. Again, I commend the hard work of the organizing committee and the eight sponsoring agencies. I am sure the Symposium will be an outstanding success due, in part, to your participation.

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FUNDING TOMORROW'S WATER REUSE

Lloyd C. Fowler
Manager
Goleta County Water District
P.O. Box 788
Goleta, California 93017

Reclamation and reuse of water is high on every list of priorities. It is an alternative that must be considered whenever additional water supplies are sought. Nevertheless, reclamation and reuse of water is today at a critical stage--a critical financial stage.

Water reclamation and reuse projects are not cheap. There are many viable water reuse projects that are not proceeding because of the lack of funding assistance. In California, 75 water reuse projects applied for aid from a Clean Water and Water Conservation Bond Act but only four projects were chosen to receive the 15 million dollars allocated to water reuse.

There are water reuse research projects receiving financial aid; some of these are pilot projects that will furnish a water supply. But there are only so many pilot research projects that can be justified. Practical, justifiable water reuse projects are waiting to be constructed, waiting because financial aid is not available.

How did we reach this critical stage? Years ago the local user supplied the funds to build water supply and sewerage systems. The small, cheaper projects were soon built. Larger areas needed larger, more expensive projects requiring funds beyond local capability. Reclamation and flood control have been national concerns for a long time, but it was land reclamation and agricultural water supplies that were Federal concerns in the Reclamation Act of 1902. Their irrigation water supply projects were known as wastewater reclamation projects; they reclaimed the waters wasting to the ocean.

Over the years other purposes were added to the Federal aid programs, including urban water service. Sewage remained a local responsibility until the passage of the Clean Water Act in 1972. It became a national goal to reduce pollution and clean up receiving waters. Sewage treatment projects became eligible for massive Federal grant funding. This was an opportunity to finance water reuse projects, projects that were a natural extension of wastewater treatment processes, and aid the water clean up program by reducing even further the pollution load introduced by system effluents into the receiving waters.

Unfortunately, the costs of full secondary treatment of every sewage discharge is high and a shortage of Federal funds soon set in. Water reuse projects were eliminated from eligible project funding with first priority on funds going to minimal treatment necessary to meet receiving water criteria. Reclamation and reuse of water was effectively eliminated from financial aid under the Federal Clean Water Act except as an incidental by-product.

Water reuse projects are again on their own; or are they? True, no 75 percent Federal grant funding is available but there are other programs that under special circumstances may aid water reuse projects.

There is assistance in the form of low interest loans from the Farmers Home Administration if the community served is rural (population of less than 5,000). There are also loans available from the U.S. Bureau of Reclamation under the Small Reclamation Projects Act (PL 984) if agricultural irrigation is included. Perhaps these programs need amendment to specifically point out the priority that should be given to water reuse projects. If we hunt, there may be other Federal programs that could be of assistance to water reclamation and water reuse projects.

Then there are potentials for local or State aid. In California, a measure is working its way through the Legislature to provide direct grant funding for water reuse projects that are not eligible for Federal assistance. This measure, AB 1200, besides funding State aid for sewerage projects would provide 100 million dollars for such grants if a bond issue is authorized by the voters in 1982. CAREW, the California Association of Reclamation Entities of Water, had proposed a 500 million dollar bond issue, one-half loans, one-half grants, to fund water reuse projects but withdrew its action when AB 1200 was amended to include a major financial program for water reuse projects. Other States could initiate similar measures for the support of water reuse projects.

There are always the do-it-by-yourself approaches. The use of revenue bonds, pay-as-you-go financing, joint exercise of powers agencies, non-profit lease back corporations, etc. But these all have drawbacks, not the least of which is the present high cost of interest on loans under these programs.

One other thought may be worthy of consideration. Why not have a Federal water reuse program similar to the 1902 Reclamation Act. Make it a nationwide revolving fund loan program to support water reuse projects. The concept is already in action; all that is needed is initial funding and a set of rules to go by.

Should water reuse projects be a national priority? Consider these reasons for such national support. Water reuse projects will help support the national economy as do other construction programs. Water reuse projects will result in improved drinking water standards; the more we practice water reuse the more we will learn about water quality and this water quality information will aid the establishment of adequate drinking water standards. Water reuse projects will reduce the dependency on new water supply projects and their potential adverse effects on the environment. Water reuse projects will reduce the pollution loading imposed on receiving waters (already a Clean Water Act goal).

Water reuse should be a national priority. Why not help to make it a viable priority by establishing a water reuse loan program similar to the 1902 Reclamation Act?

WATER RESEARCH ACTIVITIES NEED BETTER FOCUS

Lewis M. Ogles
Senior Evaluator
U.S. General Accounting Office
441 G Street, N.W.
Washington, D.C. 20548

INTRODUCTION

The United States has an abundant water supply, but its geographical distribution and availiability often do not match demand. This condition, magnified by the Nation's increasing population, industrial development, and agricultural production, has led to water shortages and increased competition for the available supply. To meet these demands, the United States may have little choice but to construct more dams, reservoirs, and conveyance systems; transfer water from one basin to another; and/or develop and implement conservation and augmentation technologies, such as wastewater recycling and reuse.

Obviously, there is no single solution to solving water quantity and quality problems. Nevertheless, developing and implementing conservation and augumentation technologies could play an important role provided appropriate congressional action is taken. Also, improved coordination of all water-related research activities could increase the likelihood of solving water problems.

On June 5, 1981, GAO issued a report entitled "Congressional Action Needed to Provide A Better Focus on Water-Related Research Activities" (CED-81-87). GAO recommended that the Congress amend the Water Research and Development Act of 1978 to:

--Require that conservation and augmentation technologies be comparatively assessed to assure that those with the most potential receive the highest level of Federal funding.

--Require that formal plans be prepared to guide research efforts to improve the likelihood of successful technology development and implementation.

--Assign responsibility for coordinating water research to the Water Resources Council provided the Congress believes it desirable to have an independent Council chairperson and resolves the issue of the Council's continued existence. Otherwise, the Congress should establish a water resources research committee under the direction of the Office of Science and Technology Policy.

This paper summarizes the main points discussed in the report.

TECHNOLOGIES SHOULD BE COMPARATIVELY ASSESSED

GAO believes an overall comparative assessment of conservation and augumentation technologies is needed to determine which have the most potential for solving water supply and quality problems at the lowest cost and with the least risk.

GAO found there does not appear to be a correlation between the potential of some technologies and their relative level of Federal funding. Some appear to have low potential but high funding; whereas others appear to have high potential but low funding. For example, cloud seeding has received considerable Federal attention, but its potential for increasing usable water supplies is uncertain. By contrast, evaporation reduction by destratification may have considerable potential but it received no Federal funding during fiscal year 1980 and it has never received over a few thousand dollars. An April 1980 study by the University of Arizona's Water Resources Research Center ranked destratification as having more potential for meeting Tucson Arizona's future water demand than other alternatives, including cloud seeding, desalting, and various interbasin transfers.

Although not specifically addressed by GAO, the author believes recycling of industrial wastewater is another area which appears to have considerable potential. An April 1979 report entitled "Water Reuse and Recycling Volume 1, Evaluation of Needs and Potential," sponsored by OWRT indicates that the gross potential for making more efficient use of water supplies through increased wastewater recycling is substantial. The report estimated that industrial recycling in Califorania could increase from a 1975 level of 5.8 billion gallons per day to 23.8 billion gallons per day by the year 2000. This would be equivalent to about 20.2 million acre-feet per year. Even more interestingly, the report concluded that recycling in the Texas Gulf region could increase by 111.8 billion gallons per day, or about 125.2 million acre-feet per year, during the same period.

Factors to Consider in Assessing Technologies' Potential

An overall comparative assessment or ranking of technologies should be preceded by regional and local assessments because

--potential solutions to water problems may differ among regions, and localities, and

--the best solution for one area may not be the best for another area.

Basically, an overall comparative assessment of technologies would be a ranking of the results of regional and local assessments.

In doing a comparative assessment, all regional and local water problems and potential solutions should be identified.

Potential solutions could include developing and implementing one or more conservation and augmentation technologies; constructing more dams, reservoirs, and conveyance systems; transferring water from one basin to another; and/or curtailing demand. Also, as previously noted, potential solutions may vary depending on the region or locality being reviewed. For instance, evaporation reduction by destratification may be a viable option for solving Tucson, Arizona's water problems. However, it may not be practical in many other areas.

Another major aspect of a comparative assessment of technologies involves assessing the impact of technical, environmental, legal, and social obstacles. A technology's gross potential for solving water problems may appear to be substantial, but the eventual contribution the technology makes toward solving water problems may be severely limited unless these obstacles are overcome. For example, public and user perceptions about the health problems associated with recycle and reuse of wastewater may prevent widescale implementation of the technology. In assessing a technology's realistic potential, 1/ a decision must be made as to what impact these obstacles will have on eventual implementation or transfer, and what action, if any, can be taken to overcome the obstacles.

FORMAL PLANS SHOULD BE DEVELOPED

Completion of an overall comparative assessment of technologies should provide a sound basis for establishing funding priorities for the technologies. However, this is only the initial step. Technology development, and/or transfer must still take place, and successfully, before the objective of increasing usable water supplies is achieved.

GAO believes that formal planning can assist technology development and increase the likelihood of user acceptance. It can tie research from a variety of sources into a program to better assure the efficient and effective development of a technology. Without plans research results may sit idle, programs may be prolonged with no determination as to whether objectives have been satisfied, and technical, environmental, legal, and social obstacles may not be adequately addressed and dealt with.

A plan for developing a particular conservation or augmentation technology should be a formal mechanism which identifies the tasks needed to develop the technology and encourage user acceptance. It should be considered a

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1/Realistic potential, as used in this paper, refers to the likelihood of a technology solving water supply and quality problems after considering the obstacles that may inhibit success, such as technical (including cost), environmental legal, and social obstacles.

"living management tool," changeable as necessary to reflect current research results and expectations. A plan should include such elements as

- --specific measurable objectives;
- --identification of additional needed research and development;
- --milestones, including an estimated program termination date;
- --technology transfer goals, including identification of obstacles and how they will be overcome; and
- --independent periodic evaluations.

Although the benefits of using plans to guide research efforts are difficult, if not impossible, to prove, GAO believes that planning could help tie many agencies applied research projects into meaningful programs to conserve or augment water supplies. Also, each Federal organization would have a better basis for requesting changes in funding levels because it could explain the impact its work has on the overall technology development effort.

WHO SHOULD COORDINATE WATER-RELATED RESEARCH?

The Water Research and Development Act of 1978 stipulates that the President should clarify agency responsibilities for water research and make arrangements for implementing interagency coordination. However, no single organization coordinates water research on a continuing basis as required by the act.

GAO examined past and current Federal efforts at coordinating water-related research and the need for an organization to be specifically assigned this responsibility. Also, GAO examined the advantages and disadvantages of various organizations having responsibility for carrying out this function on a continuing basis. Among the possibilities, GAO preferred two of the alternatives.

Of these, GAO believes the Water Resources Council, a Federal entity responsible for assessing the adequacy of the Nation's water supplies, should be assigned this responsibility provided the problems discussed below are overcome. It currently is responsible for assessing the Nation's water supply situation and identifying regional and local water problems. Water research coordination would be a logical extension of this responsibility, because regional and local water problems must be known before the potential of various technologies can be adequately determined. Nevertheless, agency officials and researchers expressed the following concerns which they believed would impede effective coordination by the Council.

- --The Council does not have the independence or authority needed to be effective.

- --The Council's continued existence has been questioned. This has hampered the Council's ability to recruit and retain an effective work force.

If these problems are not resolved, GAO believes that establishing a water resources research committee with representatives from the major agencies involved in water research could be an effective alternative, provided that

- --the committeee reports directly to the Office of Science and Technology Policy and

- --the Office of Science and Technology Policy has the ability to redirect research funding to reflect priorities established by the committee.

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THE OUTLOOK FOR FEDERAL SUPPORT OF WATER REUSE

Merna Hurd
Associate Assistant Administrator for Water
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

INTRODUCTION

Money is on all our minds. Few Federal programs have remained unscathed by budget cuts or untouched by new policy directions. Water reuse is no exception.

This is where I'd like to direct my remarks this morning: the outlook for Federal support for water reuse over the next few years.

EPA WATER REUSE POLICY

EPA recognizes the potential economic importance of water reuse in coming years. Many recent studies contain predictions of more frequent water shortages over the next two decades. As a result, economics will play a much stronger role in the allocation of water among competing uses. This will be particularly important for Western States and the high plains area.

In the future we should expect State allocation discussions to reflect a more realistic matching of demand (including water quality considerations) with available water supplies. In this context, EPA recognizes that wastewater reuse can offer significant benefits that have not been adequately understood. It can release higher quality supplies for sensitive uses. It can remove additional pollutants. And in some cases, it may be used to improve water quality.

EPA wastewater reuse policy remains unchanged. We firmly support non-potable reuse. The value and cost-effectiveness of non-potable reuse has been proven across the country in industrial applications, in agricultural uses (e.g., irrigation), in ground water recharge, and in recreation. Perhaps the greatest potential for reuse lies in freeing up existing ground and surface supplies for drinking water and other uses requiring high quality. A substantial portion of the savings realized by EPA's "Innovative and Alternative" program (I & A) has been due to non-potable reuse.

However, EPA still cannot make any recommendations about potable reuse of wastewater. We believe that too many unknowns remain to make any endorsement, and no criteria for human consumption are available based on water supplied from wastewater. EPA will continue to make no recommendations until further results come in.

Even so, Federal support has been available for a wide variety of reuse activities.

CURRENT FEDERAL PROGRAM

As most of you know, the chief sources of Federal funds for water reuse projects have been the Clean Water Act and the Safe Drinking Water Act--

particularly the Innovative and Alternative provisions of the Clean Water Act's wastewater treatment construction grants program.

Innovative and alternative technologies include projects which advance the state-of-the-art of waste management and proven alternatives to conventional management techniques--for example, land treatment. They can also include water reuse, pollutant recycling, and projects which cut energy requirements, reduce operating costs, or otherwise improve cost-effectiveness.

Since 1978, the Clean Water Act has required each State to set aside 3% of its construction grant allotment for innovative and alternative projects. A minimum of 1/2 of 1% must be earmarked for innovative processes. To qualify for funds, I & A projects must cost no more than 115% of the most cost-effective conventional treatment technology. Qualifying projects have been eligible for 85% Federal funding rather than the usual 75%, the extra 10% coming from the set aside.

In addition to I & A, rural States (those having 25% or more rural population) have had another 4% of their allotments set aside for treatment projects in towns with less than 3,500 people or in highly-dispersed sections or larger communities. At their governor's request, other States can also opt for this set aside up to a 4% maximum. Eligible rural projects receive 75% Federal funding allocated from the rural set aside. They may also qualify for an additional 10% from the State's I & A set aside.

As of last April, EPA had awarded 675 innovative and alternative grants. Early this year, the program passed the $1 billion mark, but for every $1 invested, $6 have been saved--when water reuse and nutrient recycling are factored into the calculations. Many water reuse projects have been funded around the country.

- In Northglenn, CO, treated municipal effluent will be reused for irrigation. In exchange for the treated water, farmers will provide Northglenn with well water (to be used as a drinking supply) at a ratio of 1.1 (effluent) to 1.0 (well water).

- In Baltimore, the Bethlehem Steel Company uses municipal secondary effluent for a wide variety of industrial purposes, including, cooling, gas cleaning, fire protection, air conditioning, and road equipment washing. Baltimore saves $200,000 per year on chlorination costs. In addition, the company's steel finishing operation produces a pickle liquor that is being used to reduce the phosphorus in the City's discharge to the Back River. The city will save millions in chemical costs, and Bethlehem won't have to build a treatment plant for the pickle liquor.

- St. Petersburg, FL reuses its secondary effluent for local spray irrigation and for industrial purposes. By avoiding an expensive AWT plant and by reducing energy and pumping costs, the City saves $3 million per year.

- In California water is reused for ground water recharge at five different operations--three for replenishing supply and two to prevent saltwater intrusion.

But let's take a look at what you can expect in the next year.

FUNDING

Like everything else in the environmental area, the construction grants program (including I & A) has been caught up in the current round of budget cuts. These cuts are a central feature of President Reagan's effort to revitalize the economic health of the country. At the same time, the Administration is interested in improving the cost-effectiveness of the construction grants program, in stepping up the return on the Federal dollar. To accomplish these goals, major legislative and regulatory reforms have been proposed.

EPA Administrator Gorsuch presented these proposals last month in testimony before the House Subcommittee on Water Resources. The thrust of EPA's new direction is simplifying, deregulating, and delegating the construction grants program. More and more, the Agency will be looking for ways to "shift the decision-making process from the shores of the Potomac to local governments and State capitols."

While no funds have yet been recommended for construction grants in FY 82, the Administration is prepared to adopt $2.4 billion when Congress approves its reform package (S-975). Furthermore, $1.7 billion in unobligated construction grant funds were recinded last June. This canceled out some of the FY 81 money that many States could have applied to I & A projects. Fortunately, less than 10% of the potential set-aside was lost, and many projects will continue.

LEGISLATIVE REFORMS

The proposed legislative reforms are aimed at focusing resources on the highest priority needs while lowering the overall cost of the construction grants program. First, grant assistance eligibility will continue to be limited to treatment-related project categories. These include secondary and advanced waste treatment, cost-effective alternatives such as on-site systems or small community systems, and new interceptors. These were essentially the grant eligible categories before the 1972 Act. Projects to correct infiltration/inflow, rehabilitate sewer systems, construct collector lines, or control combined sewer overflow are excluded. Water reuse projects will continue to be required to serve treatment-related needs.

The Administration has also asked that construction grants (Step 3) only be used to create capacity for existing community needs based on 1980 population figures. Facility planning (Step 1) and design (Step 2) for existing and future population will remain eligible for grants.

Together these proposals are expected to lower the Federal share of estimated treatment needs from $90 billion to $23 billion. Because construction grants will be geared to existing population only, State and local governments should have a greater incentive to reexamine their priorities and investigate the feasibility of innovative and alternative technologies. This leaves the door open for water reuse projects when they meet specific water quality purposes.

The legislative proposals also address State priority lists for grant eligible (i.e. treatment-related) projects. Setting project priorities remains a State responsibility. In keeping with the objective of cost-effectively targetting limited Federal funds, however, priority will be given to projects in urban-industrial areas that will show significant public health or water quality benefits. Thus, the chances of a water reuse project being funded increase if it addresses a high priority problem.

Besides the priority lists, States will have greater flexibility in setting aside funds for rural and for innovative and alternative projects. The Administration has proposed that the current mandatory set asides be dropped in favor of future set asides at a governor's request. This effectively transfers decision-making on water reuse projects to the governor's office, which, in the future, must request set asides for both I & A grants and rural grants.

In her testimony, EPA Administrator Gorsuch noted that "EPA strongly supports the innovative and alternative and the rural programs. We will continue to devote significant resources to further the implementation of these programs. In administering them, we have become convinced that States need more flexibility in tailoring the use of available funds to their particular needs."

ADMINISTRATIVE REFORMS

Other than funding allocations, the statutory requirements for water reuse and other I & A projects have changed very little. Substantial administrative changes, however, are in the works to increase State and local decision-making perogatives and streamline the regulatory process.

Except for statutory requirements, almost all regulations for the construction grants program are being revised. The changes under consideration may include:

-- simplifying regulations to specify outputs rather than procedures
-- dropping unnecessary requirements
-- reducing the volume of regulations
-- providing guidance
-- soliciting State and local input on new proposals
-- swiftly implementing new regulations.

Another possible change, new requirements would be published only once each year, just before the beginning of the new fiscal year, and would not be retroactive.

Already, 34 of 47 program requirement memoranda have been dropped for being unnecessary or duplicative. These are policies with which all construction grant projects have had to comply. Facility planning requirements have also been reduced substantially and are now available in a single bound volume. The innovative and alternative requirements still remain as an important factor in facility planning.

MULTIPLE-PURPOSE PROJECTS

Another area I'd like to briefly mention is multiple-purpose projects. While EPA strongly supports I & A projects, some confusion still exists about multiple-purpose projects. In this case, I'm referring to wastewater treatment projects which are doubled up with reuse operations.

There has been no change in EPA policy on multiple-purpose projects. This policy involves application of the Alternative Justifiable Expenditure (AJE) cost allocation procedure. Under this procedure, grant eligible costs are limited to costs directly attributable to pollution control plus some portion of the shared costs. Costs not related to pollution control are not eligible. Generally speaking, the grant eligible portion of a multiple-purpose project will be less than that for a comparable single-purpose control project.

Some multiple-purpose projects (including wastewater reuse) have met I & A requirements. As long as they cost no more than 115% of the most cost-effective conventional alternative, they are eligible for 85% Federal funding.

In as much as they promote cost-effectiveness, EPA will continue to actively support multiple-purpose projects.

RESEARCH

The last area I want to touch on is research. Congress has invested $7 million in the Denver Water Department's $22 million, high-technology potable reuse plant. This plant will produce 1 mgd, and the results on plant performance and effluent quality will be available in the late 1980s. The Denver project will set the stage for development of EPA policy on potable reuse. In addition, an epidemiology study in the Montebello Forebay area in California has been partially funded with EPA dollars. This project is studying the health effects of using AWT effluent for ground water recharge purposes. Results should be available this December. Next spring, results should be available from an EPA study of a similar AWT/recharge effort in Nassau County, New York. This study examines the removal of toxic pollutants from the AWT effluent.

Besides government activity, the private sector has shown interest in wastewater reuse. It is very encouraging to see research moving ahead on other fronts. Industries are beginning to see the potential of wastewater in cooling and other processes. In the West, farmers are tapping wastewater as a source of irrigation water. And one computerized, on-site, potable reuse system is now on the market for $15,000 with a $35 per month operating cost. The National Sanitation Foundation is studying its performance. In all of these cases, market forces are proving the value of reuse. While the ready availability of ground and surface water makes reuse economically unsound in many (if not most) areas, water short areas are finding out just how effective a source of water reuse can be.

CONCLUSION

EPA recognizes the importance of wastewater reuse as a potential solution in both water supply and water quality issues. EPA still strongly supports the innovative and alternative provisions of the Clean Water Act. Through the Reagan Administration's legislative and regulatory initiatives, we hope to make this program and the construction grants program more cost-effective and more responsive to State and local problems.

The initiatives do not diminish the statutory requirements for I & A or reuse. They will, however, streamline the regulatory process, making it easier for State and local governments to tailor their wastewater management programs to their specific needs. The initiatives also place the I & A ball squarely in each State's court--through construction grant priority lists, through set aside requests, through State funding support, and through interest in finding cost-effective alternatives to conventional waste management.

The future of wastewater reuse will depend largely on private market forces. Water short areas may come to rely on reuse for non-potable uses, and as the technology becomes available, potable reuse may become feasible on a wider scale. The possibilities are promising. As for public support for reuse, proponents will need to focus their activities at the State and local levels. City councils, mayors, county councils, State legislatures, and governors all have the opportunity to take the lead in innovative and alternative technologies. We hope they will take it.

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The National Science Foundation's Role in Support of Research Applicable to Reclamation of Wastewater and its Reuse

by

Edward H. Bryan
Program Director, Water Resources and Environmental Engineering
National Science Foundation
Washington, D.C.

Science has played an important role in development of our present understanding of all matters relating to water and this knowledge has been applied by engineers in solving problems relating to its availability, quality, use, renovation and reuse. The roles of science and engineering as they relate to management of water are becoming progressively more important as pressures increase for more intensive use of available water supplies.

Since its establishment in 1950 as an independent agency of the Executive Branch of the Federal government, the National Science Foundation (NSF) has provided support for research that has not only continued to broaden the base of understanding on topics directly and indirectly relating to water but has contributed solidly toward application of this knowledge to solving problems that are associated with the management of water. Research is an important, distinctively human activity, that is best characterized as a careful, diligent effort aimed at the discovery and interpretation of facts and interrelationships between causes and effects leading to the formulation of natural laws which can be used predictively.

The search for knowledge and its application to manage our water resources may be considered as an attempt to seek correspondence between principles that precisely govern physical, chemical and biological relationships with those that form the basis for social and institutional interactions. It may also be viewed as a manifestation and extension of the uniquely human attribute known as intelligence applied to the characteristic humans share with all other living organisms, viz., the need to successfully cope with issues that threaten the survival of the species.

The earth ecosystem may be viewed as an integrated collection of living species that have evolved to provide linkages in the movement of substances along an energy gradient. Residuals from one species become resources for others. Water functions as a transport medium cycling at all scales from molecular to global(1). Considered broadly, almost all of the research that the Foundation supports has some relevance to water, one of the three media comprising the earth and with which all living creatures interact.

Research is likely to be called "basic" if it stops short of dealing with practical applications of the results and "applied" if has as its objective the application of knowledge to the solution of problems. To distinguish between basic and applied research, we may have to probe the motives of the person doing the research, and there's some question as to whether such probing is of any lasting value. The terms "basic" and "applied" seem better adapted to describe relationships between projects and programs on a relative scale, i.e., one body of research may be "basic" with respect to another but "applied" when compared to something else.

Research can only contribute toward solutions because, playing as it does a role between the unknown and the known, it needs linkages with the "practical". There is a world of difference between experiments conducted on a laboratory bench in a university by a doctoral candidate to obtain data for a dissertation that adds incrementally to knowledge, and the successful application of a process based upon that knowledge in full-scale, day after day, week after week, and month after month to meet technical and economic criteria for success. Development is the process during which the credibility of a concept or process is measured, that is, the difference between what research promises and what people can deliver.

Basic research, applied research, proof of concept, development, demonstration, public acceptance and evaluation is the usual sequence with which progress toward reality from the "unknown" is accomplished. These stages differ markedly in the amount of resources needed to sustain them. The costs of research leading to the solution of a problem usually turn out to be less than development and demonstration stages. This results in part from the impracticability of identifying the fair share of the cost of basic and applied research that went into building the foundation for the advances in sciences and engineering assignable to specific advances in technology. As a consequence, the support of research in the public interest must often be argued for on the basis of faith in its potential value in addressing future problems and issues rather than a demonstrably high ratio of benefits to costs.

The allocation of resources in support of the search for better understanding of human impacts upon the earth ecosystem as represented by the cycling of water are the product of complex, institutional arrangements for meeting a variety of needs. The mechanisms for proper allocation of these resources are imperfect. It would, of course, be helpful if we had the knowledge we seek in making judgments on how to allocate our resources to accommodate properly our needs of the present and for meeting the conditions of our future.

The trend during the past generation toward loss of confidence in the abilities of scientists and engineers to deal constructively with current problems appears to have slowed, if not as yet reversed. Preliminary results of a survey conducted by NSF were recently reported by Kristof(2) to have shown that of those persons interviewed, the ratio of those who felt the benefits of science outweighed the harms was 6-to-1. However, that same survey also indicated a reversal in the prior generalization that "the younger people are, the more favorably disposed to science they are". Perhaps it is the inability of science and technology to provide more definitive guidance in value-judgments that periodically leads to loss of confidence by the public in the values of research as an investment toward a future.

One way to view the immediate future is to look upon it as a time when we can continue to search for better solutions, develop those in which we have the most confidence and commit resources as efficiently as possible toward meeting reasonable needs. In his essay "The Tragedy of the Commons", Dr. Garrett Hardin wrote that:

> "Injustice is preferable to total ruin...we can never do nothing. That which we have done for thousands of years is also action. It produces evils. Once we are aware that the status quo is action, we can then compare its discoverable advantages and disadvantages with the predicted advantages and disadvantages of the proposed reform. On the basis of such a comparison, we can make a rational decision which will not involve the unworkable assumption that only perfect systems are tolerable."(3)

Good management may be defined as the art of making wise decisions in the absence of all necessary information. To the extent that knowledge is inadequate, judgment must be exercised while research to provide better bases for decisions is undertaken. The analysis of error and its correction is the essence of the "engineering method". It is a powerful methodology for making progress.

The National Science Foundation's role in supporting research applicable to reclamation of wastewater and its reuse is to provide a better understanding of water-related issues subject to scientific inquiry, leading to a better foundation for the empirical practices and procedures that characterize the practices of water resources and environmental engineering. It seems evident that the reclamation of wastewater and its use must be an essential part of any strategy that realistically addresses our future problems relating to water. Research, as our societal mechanism for guiding us into the "future", is an essential part of the process by which we obtain the basic knowledge and learn to apply it toward solving the many problems we face as pressures mount for reuse of available supplies of water.

To obtain and sustain the necessary levels of support for research, we will have to work diligently to retain and hopefully increase public interest and confidence in research as a worthwhile investment toward a future. However, in this respect, we cannot ignore what Octavio Paz(4) characterized in his essay on "The Discovery of the Present" as: "...the general doubt about progress" as characteristic of our time...a time when we seem to have rejected concepts of both the past and a future to live "in the now". He suggested, however, that we need not despair disappearance of the past and future from our culture because: "The present reconciles us with our reality: We are mortal".

Research to gain knowledge and application of that knowledge to the solution of problems must be recognized as complementary to but not a substitute for reasonable action. To delay reasonable action in the name of research is likely to reduce public confidence in both research and reasonable action. The adoption of current technologies to deal with current problems will lead to the identification of deficiencies toward with further research may be directed for better solutions. This seems to be the most reasonable course for progress toward another "now".

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FUNDING OF WATER RECLAMATION PROJECTS IN CALIFORNIA

Kurt Wassermann
Chief, Office of Water Recycling
California State Water Resources Control Board
77 Cadillac Drive
Sacramento, California 95825

INTRODUCTION

California is facing a severe water shortage. It is estimated that by the year 2000 the annual shortage will be about 4.3 milion acre-feet. This assumes normal rainfall and completion of currently proposed state and federal water development projects. If these projects are not constructed, the annual water shortage will be 6.6 million acre-feet. Of course, water shortages and droughts are not the perogative of California. Recently, New York, Delaware, New Jersey, and Florida experienced serious water shortages. Development of oil shale resources in Colorado, Wyoming and Utah will stress water supplies of these areas. It is clear that many areas of the United States need to develop water resources management alternatives which include water conservation, conjunctive use of surface and groundwater, better groundwater management, and water reclamation.

Water conservation and reclamation are essential to meet the future needs of California. It has been projected by the California Department of Water Resources that, by the year 2000, water conservation and reclamation have the potential to reduce the water demand by at least 2.4 million acre-feet per year. About 600,000 acre-feet of municipal wastewater could be reclaimed, provided construction funds can be secured.

In the past, many of California's water reclamation projects were developed because water reuse was an integral part of a pollution control project and eligible for grants under the federal Clean Water Act. At least 80 water reclamation projects have proceeded to design and construction under California's Clean Water Construction Grant Program. These projects are making available as much as 200,000 acre-feet of reclaimed water per year for agriculture, landscape irrigation and groundwater recharge. Several reclamation projects were implemented by local agencies without state or federal assistance because reclaimed water was available for free or low cost. In some instances, stringent standards for waste discharge to surface waters encouraged water reuse.

To accelerate California's water reclamation effort, Governor Brown established the Office of Water Recycling during the severe drought of 1976-77. He set a goal of reclaiming an additional 400,000 acre-feet per year of wastewater by the end of 1982. This goal was based on the assumption that funding would be available under the Clean Water Act for water reclamation projects, including projects planned as a water supply and not needed to meet enforceable pollution control requirements.

Because of the California State Water Resources Control Board's policy to encourage reclamation and attain the Governor's reclamation goal, local agencies and municipalities were encouraged to apply for State and Federal grants for facilities planning. A major consideration for assisting local agencies with facilities planning was the fact that billions of dollars are being spent to build or upgrade wastewater treatment plants. Without reclamation, much of the highly treated effluent will be wasted to the ocean.

During the last three years the State Water Resources Control Board (SWRCB) awarded grants to about 40 local agencies for water reclamation planning studies. The main objective of this planning effort was to identify and develop markets for reclaimed water. Cost-effectiveness and financial feasibility were major considerations in these studies. These projects range from small local projects to regional projects with markets of up to 375,000 acre-feet per year. The local agencies started this planning effort with the understanding that cost-effective water reclamation projects would be eligible for funding under the Clean Water Act. On the bases of a U.S. Environmental Protection Agency (EPA) decision in 1979 not to fund three California wastewater reclamation projects, it is now clear that water reclamation projects with the purpose of water supply are not grant eligible.

NEED FOR FUNDING ASSISTANCE

While the need to expand the use of reclaimed water in California is clearly evident, there are the following economic constraints to increased water resue in California.

- The cost of most present water supplies is relatively low. This is due mainly to the supplies coming from the most easily developed sources, especially from groundwater. In the short run, it is cheaper to over-draft than to reclaim.
- The price the consumer pays for water is usually based on an average cost of existing sources of water, not on the incremental cost of new, more expensive sources. Also, the price is subsidized by cheaper electric energy for large water projects and, in some instances, by the use of ad valorem property taxes.
- The cost of constructing and operating a water reclamation project is in many cases substantial. Local projects do not have the advantage of lower cost energy as do large water development projects, such as California's State Water Project and the federal Central Valley Project.

While federal pollution control grants can be used for wastewater treatment to levels required by waste discharge requirements, the local sector must pick up all the costs of any additional treatment and the needed distribution system for reclaimed water. Besides the purchase price of the reclaimed water, customers may have added costs of using reclaimed water of lower quality than fresh water. For a reuse project to be cost-effective and implementable, a project must be economically justifiable and price competitive with the available fresh water.

While the cost to construct and operate most water reclamation projects is competitive with the cost of developing new surface water supplies, the price water users would have to pay often make reclaimed water uncompetitive in the market place. It is therefore essential for most water reuse projects to receive funding assistance to be financially viable.

The benefits of grants to assist local agencies with the construction of wastewater reclamation projects can be best described with an example. The Walnut Valley Water District, near Los Angeles, has proposed a reclamation project that would develop water at a cost of $286 per acre-foot. To meet future water demands of the District, new Northern California water could be developed and delivered to its customers at an estimated total cost of about $440 acre-foot. However, the price customers would pay for Northern California water would be significantly less than the cost of reclaimed water. The capital costs of the new supply would be merged with the initial costs of the State Water Project, resulting in a lower average price.

A funding related issue is: Who receives the benefits and who pays? When, for example, a local agency replaces its imported water with reclaimed water, the released fresh water is then available for use by others. Others may be the water wholesaler, the State of California or the federal government. In addition to reduced freshwater demand, there may be energy savings due to reduced pumping. It is important that costs are shared equitably by the beneficiaries.

PAST STATE FUNDING EFFORTS

Past efforts to provide State funds for water reclamation projects resulted in very limited success. When California voters approved the Clean Water and Water Conservation Bond Law of 1978, $50 million were earmarked for grants for projects ineligible for federal assistance. Recently, $13.4 million from this fund were made available by the State Water Resources Control Board for design and construction of four water reclamation projects. These projects will reclaim 5200 acre-feet annually. Local interest in water reclamation is evident by the fact that agencies applied for a total of $82 million in grants from this source for reclamation projects.

In 1979 the concept of a state funded Renewable Resources Investment Program was developed. The state Legislature made an initial appropriation, including $4.5 million for a reclamation project. To continue the program, a $500 million bond issue, including $77 million for water reclamation, was placed before the voters in June 1980, but it was defeated.

In 1980 the California Legislature established the Engergy and Resources Fund with an allocation of $120 million annually from tideland oil revenues. The funds are to be used for energy and natural resources development, a very broad category of potential uses. Altogether 18 programs and project areas were identified in the law. Water reclamation projects would be eligible for funding. However, an attempt by the State Water Resources Control Board to obtain $35 million in fiscal year 1981-82 for reclamation projects was unsuccessful. Prospects for obtaining funds from this source for reclamation in the years to come are somewhat dim, in light of possible diversion of tideland oil revenues to the other state programs.

PRESENT FUNDING ALTERNATIVES

The following is a brief summary of potentially available funding alternatives for water reclamation projects in California. Federal, state or local funding, or a combination of the three, may be possible for projects meeting certain criteria.

Federal: U.S. Bureau of Reclamation (USBR) and the Small Reclamation Projects Act

At the federal level, the USBR is responsible for water development in the western United States. While in theory, the Bureau can develop a water reclamation project in lieu of a conventional water supply, its activities focus almost exclusively on larger, regional projects. One example of the involvement of the Bureau in local water reclamation is the Ventura County Water Management Project Feasibility Study. The proposed plan included supplying reclaimed water for agricultural use.

The Bureau is not set up to integrate efficiently local water reclamation projects into its water development activities. Water projects are typically justified by a 4 to 5 year feasibility investigation which is often preceeded by a 2 to 3 year appraisal investigation. Each feasibility investigation is individually authorized by Congress, funds must be appropriated, and final designs completed. The time interval from initiation to start of construction is 6 to 8 years at a minimum, and 10 to 20 years is not uncommon. The advantages of a Bureau financed project is, of course, no interest charges or comparatively low interest rates and a long repayment period.

The Small Reclamation Project Act of 1956 (Public Law 84-984), as amended, established a program under which certain public entities, located in 17 western states and Hawaii, can obtain loans or grants for small water projects. A small project may be a complete single-purpose irrigation, irrigation drainage, or multiple-purpose water resource project. The maximum loan and/or grant is set at 2/3 of the maximum total project cost. The maximum total project cost for calender year 1981 is $35,800,000. There is also a provision for handling cost escalation.

All loans and/or grants are subject to Congressional appropriation. Grants may be made for flood control, outdoor recreation, and fish and wildlife enhancement. Loans may be made solely for irrigation or for drainage of irrigated lands or for multi-purpose projects eligible under federal reclamation laws. Multipurpose projects may include irrigation, drainage, industrial or municiapl water supply, fish and wildlife enhancement or outdoor recreation. Irrigation must be for commercial agriculture. Loan funds cannot be used for construction or upgrading of treatment plants, or acquisition of water rights or rights of way. Portions of the loans allocated to irrigation and drainage are interest free.

Loans and grants may be obtained by a state, or a department, agency, or political subdivision thereof. Additionally, conservation districts, irrigation districts, water users' organizations or similar organizations which have capacity to contract with the United States under federal reclamation laws are eligible.

State: The State Water Project, and the Proposed Clean Water Bond Law of 1982

The California Department of Water Resources (DWR) has authority to add local water reuse projects to the State Water Project (SWP). The massive SWP, constructed in the sixties at a cost of about 3 billion dollars, provides Northern California water for the Central Valley and Southern California region. Thirty-one local agencies, the water service contractors, contracted with DWR to supply a "minimum project yield" of 4.23 million acre-feet annually from the SWP. Up to now, facilities to deliver 2.3 million acre-feet annually have been completed. Under guidelines issued by the Department, for local water reclamation projects to be included in SWP, they must provide a yield to the SWP service area within the annual 4.23 million acre-feet minimum project yield. Annual entitlements of each water contractor are part of the SWP water supply contracts.

Reclamation projects may be constructed and operated (1) by SWP, (2) as a joint SWP-Federal project, or (3) as a joint SWP-local agency project. Local projects added to SWP may be financed by the sale of Central Valley Project revenue bonds. In order for a local reclamation project to be considered as a unit of the SWP, the local project must be technically and financially feasible, economically justified and environmentally sound.

Up to now, only very few local agencies have applied, or are considering applying, for funding under the SWP. Generally, there is a great reluctance to give up entitlement to fresh water for reclaimed water. Local agencies which are already experiencing a serious water shortage and have little or no opportunity in the near future to receive additional supplies from the SWP are most interested in implementing their reclamation projects as part of the SWP. If local reclamation projects could be financed as "supplemental projects", i.e., their yield would not count as part of the minimum project yield, considerable interest would exist.

Of interest is Senate Bill 200 which authorized in 1980 construction of the Peripheral Canal and other units of the SWP. This bill also includes "water reclamation programs to provide yield for the State Water Resources Development System, provided such facilities are economically competitive with alternative new water supply sources." It should be noted that the authorization is in terms of the State Water Resources Development System, not just the SWP, so that the concept of "supplemental projects" would be applicable. However, no dollar amount for reclamation projects is included in this bill.

The Clean Water and Water Conservation Bond Law of 1978 provided $375 million in grants to local agencies. These funds will be exhausted by 1982. To continue to provide State assistance to local agencies, a new bond law has been proposed for 1982 (AB 1200, McCarthy). The Clean Water Bond Law of 1982 would provide for the issuance of state bonds in an amount not to exceed $400 million, if approved by the voters in June 1982. $300 million would be for grants to municipalities to construct water pollution control projects. The remaining $100 million would be for eligible water reclamation projects of up to 75 percent of the total construction cost. It is estimated that these grant funds, together with the local share, would provide about 60,000 acre-feet of reclaimed water annually.

Local and Regional Options

Because reclaimed water prices have to compete with existing fresh water prices which do not reflect the cost of developing additional water, total local financing of water reclamation projects has been very limited. An example of the impact of grant assistance on the reclaimed water price is a project proposed by the County of Ventura which would make available 8500 acre-feet for agricultural irrigation annually. With a 87.5% grant the $18.8 million project would provide water at $56.35 acre foot. Without a grant water would cost $236.82 per acre-foot.

In the past, projects have been funded by local agencies where water was scarce and reclaimed water was available at a relative low cost. Local funding of water reclamation for new housing and community development projects has occured in some instances. Water reclamation has and will continue to be considered in lieu of disposal, where municipal wastewater collection systems cannot serve new housing or industrial developments. Several industrial plants in California have chosen to recycle or reclaim their wastewater because of very stringent discharge requirement. Private funding of water reclamation under these circumstances will continue.

In Southern California, where most of the region's water is being imported either from Northern California through the SWP or from the Colorado River, water reclamation has two major benefits: increased water supply and reduced energy consumption. When reclaimed water is substituted for fresh water, fresh water becomes available to meet increasing regional water demands or to reduce the use of imported water. The reduced fresh water demand will save electrical energy which would otherwise be needed to pump water from Northern California to Southern California.

In 1978, the Orange and Los Angeles Counties Water Reuse Study was established to develop a regional plan for using some of the area's highly treated wastewater. The Study has identified 23 reclamation projects, totaling 220,000 acre-feet annually. Construction of many of these projects, primarily those for greenbelt irrigation, is only limited by lack of financing. The Study is presently evaluating several financing options. They include a regional-local joint venture, electric power sharing, and regional-State Water Project financing.

Under the regional-local joint venture, the Metropolitan Water District of Southern California (MWD) would enter into capital cost-sharing agreements with its member agencies and other local project sponsors.

Some reclamation projects are interested in receiving electrical power at the significantly reduced price MWD pays for pumping imported water. Under this concept, MWD would provide electric service to reclamation projects at the price paid to import water from the SWP or Colorado River. The price would be adjusted for cost differences in service connections and time of use.

The third option involves funding of local reclamation projects as part of the SWP. MWD, in cooperation with other SWP contractors, would participate in a statewide program of local project development under the financial umbrella of the SWP.

CONCLUSION

In summary, the following can be concluded regarding funding of water reclamation projects:

- In the past, many projects in California were implemented as wastewater disposal alternatives for pollution control and were funded by EPA and state grants. However, water reclamation projects which are not needed to meet enforceable waste discharge requirements, but which would provide a water supply, are ineligible for EPA grant assistance.

- Many proposed reclamation projects are cost-effective as an alternative water supply from the State's viewpoint, but are not from a local viewpoint. This is especially true where groundwater supplies are available. Since California, as a whole, and the United States are benefiting by the development of reclaimed water, it is reasonable to provide financial assistance for cost-effective reclamation projects.

- Regional financing techniques which are used to develop fresh water supplies can be used for water reclamation projects. In Southern California, this financing approach is the key to implementation of large-scale water reclamation.

- The Small Reclamation Projects Act of 1956 is a potential funding source for reclamation projects which provide irrigation for commercial agriculture. The Act should be broadened to allow grants or loans for local water reclamation projects, such as landscape and greenbelt irrigation, industrial and power plant cooling, and other beneficial uses.

- Federal water resources development efforts have focused mainly on conventional water sources. Federal water policy should recognize the significant benefits of water reclamation in certain parts of this country. Water reclamation should be evaluated as an alternative, or as a part of future water development projects. It should be given equal consideration to conventional water sources. At a time when we all strive for the most effective use of public funds, water reclamation, a potentially less costly source of new water, should not be ignored.

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FUNDING REUSE PROJECTS FROM A UTILITY POINT-OF-VIEW

Neil Cline
Manager
Orange County Water District
P.O. Box 8300
10500 Ellis Avenue
Fountain Valley, California 92708

INTRODUCTION

The challenge of formulating and implementing water reuse projects is growing progressively more difficult in the United States. The current intense competition for money for the private sector or for governmental programs compounds the challenge. Traditionally, public agencies have been able to rely on either state or federal financing programs to supplement local funding efforts. EPA had their 92-500 grant program monies, the Farmers Home Administration and the Bureau of Reclamation had their small projects, the Corps of Engineers had some projects as well as the Department of Agriculture, OSW and OWRT. However, in all those areas in the past, you had to find either a farmer you could somehow weave into the fabric of your project or some kind of flood control effort or irrigation project, or maybe enhance some lonely fish. But you always had to use your creativity to work in a water project for municipal supply and particularly for wastewater reuse. It's getting more tricky because there has been a taxpayer revolt in this country--in California, Proposition 13, for example. And when you overlay that with the obvious reduction in federal and state assistance, the public utilities are having to scratch their heads and develop alternate methods of financing necessary water projects. In California there are problems in every one.

FUNDING ALTERNATIVES

The three principle methods of financing water programs in California, particularly Southern California where we have a rapidly expanding population and demand for water, are as follows. Many are still clinging to the traditional sale of general obligation bonds. It requires voter approval now but can be successful. The City of Orange in Orange County recently passed a bond issue to put in a reservoir and some distribution facilities. They sold 10 million dollars worth of bonds with voter approval. But in order to make these bonds attractive, they had to discount them. So for five million dollars worth of bonds, they are only going to get a little less than four million dollars to construct the project. So it's not all that groovy and I'm not sure the voters of the community understood what they were voting for or that they realized what they had given away.

Another very popular, and growing method, is the so-called non-profit corporations where there is a lease-hold mortgage revenue bond system developed. It's done under the auspices of the local agency that realizes and recognizes they have a problem of water supply which they have to answer. These corporations are formed to acquire property and facilities, construct necessary works and to finance the construction and operation of these facilities. In order to qualify for these non-profit corporations, certain tests must be met. Among them: The corporation must be engaged in an activity that is essentially public in nature. It must be clear that the corporation is not organized for profit and the corporate income does not benefit any private person. The local state or local political agency has to have a direct benefit as a consequence of this organization. Once it is determined that this is a desirable method of financing a project--, the local government agency or water district Board of Directors will appoint their cousins or brothers or some other closely-related individuals to a Board of Directors. They will somewhat follow the direction of the original Board of Directors and this non-profit corporation will lease the completed facilities to the public agency at a fixed annual rent to pay the principle and interest. The funds are derived through the sales of water. The key is, if the lease hold mortgage revenue bonds are secured by revenues other than ad valorem taxes, they can be issued without a popular vote. And so that is one way we have been able to kind of finesse our way around the limitation of Proposition 13. What happens, though, is that people move into an area. They buy a house and then suddenly find themselves paying a tremendous amount of money to a non-profit corporation that they've never heard of. And it turns out it's headed by the uncle or the brother or the cousin or the consulting engineer of the local agency. This creates a certain amount of heartburn throughout the community. It's not all that popular with the people although it's popular with the developers at this time.

A third method that is getting some attention in Southern California, particularly, is special assessments. Under the philosophy that those that benefit should pay, you formulate a project, determine its cost, and determine what the benefit of each parcel will get as a consequence of that project. Then you develop an assessment against the parcel and have a series of special public hearings to discuss this. If you are lucky, not too many people know about it and the project goes through. Frequently, however, a lot of people do know about it and you have rather stormy sessions. Then it comes down to whether the public agency and the developer have the nerve to continue with the assessment program. Frequently they do. And when they do this, the landowner or those who benefit can, after the assessment has been completed, pay cash initially and clear their property of its lien. However, most people don't have the cash to pay immediately, so the remaining or unpaid assessments are represented as assessment bonds with a 10 or 20-year amortization period. Once again, you have to have a public body or a public district of elected officials that can stand up to a lot of criticisms from the community. And, politicians are politicians with nobody liking to be criticized. Therefore, that doesn't work all that well either, although it is being utilized.

Then in California we have a wonderful thing called creative financing. This is very popular in trying to sell houses. Those of you who live in California, particularly Southern California and who follow the housing market, know it's brutal. Tract houses that were selling just a few years ago for $80,000 are now running a quarter of a million dollars and the interest rates are 17-18% if you can find someone to loan you the money. However, they have this kind of euphemism called creative financing. There is a guy down the street from me who bought a house, a modest little tract dwelling. He has a first on it, a second, a third, a fourth and a fifth. And some of these come due with convenient spacing in maybe six months. I'd say in five years from now my new neighbor is going to be in a cold sweat. However, creative financing is keeping the real estate market alive in Southern California and presumably the wastewater reuse programs. When you get into the hierarchy of water projects, wastewater reuse is popular like Ronald

Reagan is with the Air Traffic Controller's Union. But we have had some fascinating ideas borne out of the reality that we must recycle water. We have a scant resource in the west, and if we are going to make proper use of our limited resources, we've got to get into the wastewater reuse business. In California, we have a legendary shortage or maldistribution of water. And one way of solving our problems will be through wastewater reuse. We're prepared to face that. In California it is not "if we have a drought", it's "when are we going to have the next one?" And during the last one in Southern California, the water from Northern California, which we've been relying on because it's such high quality, was cut off. We were fortunate that we were able to go to the Colorado River for waters. In mid-1980's, the water from the Colorado River is going to be going to Arizona. So that water won't be available to us. The next state drought will directly affect about 11 million people in Southern California. But we're prepared to do whatever we can to make sure that we can continue to provide an adequate supply of water for our residents. We consider that we will get into the wastewater reuse business in some kind of an expanded method. I work for the Orange County Water District in Southern California. We've been in the wastewater reuse business for a number of years either directly or indirectly. Indirectly, we manage the Santa Ana River, the largest river in Southern California. If you get there in December, there may be some water in it but if you get there in July you still don't see a whole lot of water in the stream. As an example of wastewater reuse, last year we had about 80,000 acre feet that came through the canyon into Orange County. We managed to capture it, sink it and put it in the sub-surface. Now of that 80,000 acre feet which was the natural runoff of the Santa Ana River, about 39,000 acre-feet had gone through the kidneys of those people upstream from us. We sank it, we're reusing it and look forward to it. We hope we can continue to keep our Regional Quality Control Board active enough so that water will be at a quality we can reuse.

To continue to supplement wastewater reuse programs in our area, Kurt Wassermann also mentioned the Orange/Los Angeles County Reuse Study, about which there has been a lot of enthusiasm by the engineers who review the program. The shining example that they site as probably the most attractive reuse program in Southern California is one called Green Acres which will be sponsored by our district, the Orange County Water District. Green Acres is a landscape-irrigation project that will provide about 2500 acre-feet initially to schools, parks, cemeteries, freeway landscaping, some minor industry or industrial uses and reclaimed water for agricultural irrigation. The difficulty is that the alternate water sources in our community are ground water which the local producer can pump. It will cost around $40 an acre-foot or they can buy irrigation supply from the local community depending on their location, for $100-$150 an acre-foot. To reclaim wastewater costs $150 to maybe as much as $300 an acre-foot. So you have to have some kind of incentive for the local agency to desire, purchase and use your reclaimed water. One method, of course, would be to not furnish them water for irrigation for parks, cemeteries, golf courses, etc. Just declare that, when we have a water shortage, their water supply will not be available--and that may attract their attention. We don't really want to do that. On the other hand, in order to stimulate interest in our water supply we make it sound like that may be a possibility. One thing we know for sure in Southern California is that water supply or the cost of water supplies will continue to increase as the cost of energy goes up. Every acre-foot of water in Orange County is pumped from someplace, either out of the underground or over the mountains in Northern California or from the Colorado River. It's all energized. And as the cost of energy increases, the cost of the water supply in our community will increase. Taking this into account, the OLAC study team has devised a fascinating funding alternative. An example of creative financing for the reuse business - the Metropolitan Water District - is the major water purveyor for all of Southern California and responsible for the supplemental sources used from the Colorado River or from Northern California. MWD would provide an equivalent of $275 per acre-foot to the local agency that builds the reuse project. In this case, they would give to Orange County, the equivalent of $275 per acre foot for our 2500 acre-foot Green Acres project. For us to be eligible for this kind of subsidy from the Metropolitan Water District, we would put into a fund some of our reserve capital (an interest bearing account). Then we would produce the water from our Water Factory 21 and supplemental systems and sell the water at around $230 an acre-foot, presumably a little lower than Metropolitan would be selling its water. So the water would be discounted to the local agency. That's what the local agency would pay as an incentive to use reclaimed water. Then between the Orange County Water District and the golf course irrigator is usually a local district. The local district would retain some of the money they get back with the $230 they collect from the golf course producer. And they would pay us maybe $50 less or we would get $180 an acre-foot for this water. We would be drawing money out of this set aside fund and we'd pool that money to offset O&M costs. Then we would transfer to Metropolitan about $175 an acre-foot (as you recall they paid us $275 an acre-foot). The benefit that Metropolitan gets is that they would be avoiding the cost of pumping this water over the Tahachape Mountains or over from the Colorado River. Presumably the difference would make it worth Metropolitan's interest. As a matter of fact, Metropolitan is interested in this project. The tricky part is trying to explain to the Metropolitan's 55 directors what I just explained to you. And we're not optimistic that can be done.

There is another method that is gaining popularity around the state. If anybody wants his own property for any purpose in California, they have to pay for the improvements, including wastewater treatment. And in those areas where there are problems with discharge, they have to pay for the recycling of the wastewater. There is an example right now in Northern California in the East Bay area. Prudential Life Insurance is contemplating developing some property but it is landlocked. They are members of a group that does pump its sewage up to the San Francisco Bay after a certain amount of treatment. But there is a limited outflow capacity to Prudential. The area is in a region where they are attracting the silicone industry and thus a requirement for a very high quality water. So Prudential, at the present time, is contemplating their own wastewater treatment facility and a reuse facility to provide a very high quality of water for industry, all at the insurance company's expense. Nothing particularly fancy, but it does work. In an area where the pressures of growth warrant it and the money is there, this is the kind of extreme measure that can, will and does happen in our state. Kurt touched on Assembly Bill 1200 where we're going to ask the people of the state to approve $100 million as part of a bond issue to be eligible for reuse projects. We're very optimistic (perhaps naively) that we will get enough support to get the bond issue through the voters. On the other hand, California's voters are, as taxpayers everywhere, suspicious of government. They're not quite certain that all this money on water projects is necessary. There is a tremendous emotional battle in the state. There are many people around the state who contend that we have enough water if we manage it properly. And there is so much confusion that I'm not sure the voters are going to understand the necessity of supporting the issue. While I say we're naively optimistic, I wouldn't want to bet on the fact that this bond issue may become a reality.We're going to have to just keep chipping away, developing modifications and creating financing. I know the Board of Directors of the Orange County Water District are progressive people. They are contemplating making available from our reserve funds a no-interest loan--just take our money and build the project. This means don't charge ourselves any interest and sell the water until we get a market going. And then at the time when Metropolitan's water prices are so high, the water we produce and market for our wastewater reuse project will be competitive. And our Board will look like heroes instead of guys who are just giving away the public trust. They are seriously contemplating that as an alternative. I think the message I'd like to leave with the group this morning is that people in the reuse business have a big selling job ahead of us. Let's face it, nobody likes to reuse water and wouldn't make that their primary choice. It's one thing to say let's reclaim water but when you actually get out there and try to do it it becomes something else. We have a lot of excited people who come to look at our Water Factory. They look at the water because it looks like a glass of gin. But when you show them the influent and they think about what happens to it and what they do to it in the privacy of their own homes, some of the zeal tends to taper off. I think we just can't lose our nerve. We know we're right. There is a lot of unanswered questions I wrote out on the airplane last night with a medical doctor. He had a bunch of x-ray films and was an expert in circulation problems. He had all of these x-rays of skulls and some infrared photography showing circulation problems in people who are about to have strokes or who have had strokes. He said, "well, what do you do?" I said, "I'm in the water business." He said, "What are you going to Washington for? You know you're not going to get any money out of Washington." I replied, "That's true--I'm going to a wastewater reuse symposium" and he expressed great concern. Now here's a scientist who feels that there isn't enough known about the health effects of wastewater for us to seriously contemplate putting this kind of water back into the environment in any way, indirect or direct, particularly direct. I tried to explain to him that the water community was so conservative that we were quite confident that we were not creating health problems. But then he raised the questions that everybody raises--that there are too many uncertainties of the long-range effects of ingestion, particularly with the increasing industrial compounds that seem to find their way into our water supply. We just don't know enough about them to safely count on using wastewater as a supplemental source. I spent about 20 minutes trying to convince the doctor that he was wrong but he remained unconvinced.

We are going to have to continue to find creative ways to finance the necessary projects. There is such a long time between the idea of developing a water supply and actually getting the project completed that we have to act now, we can't wait. Particularly in Southern California, we face critical water shortages this decade and we have to continue to move rather quickly. We have found, and it's been a fascinating experience, that we really can't rely on the federal government. The change of administration changes policy. These things happen. The money gets cut off in mid-project or before the project even gets started. As for the state, it's an emotional issue for a water supply and we can't count on them. We are going to have to count on ourselves. And I guess maybe that isn't all that bad. The United States has a very self-reliant, problem-solving type of individual. And I guess wastewater reuse is probably our next big local challenge. I feel that we will expand our wastewater reuse efforts and supplemental supply in Southern California."

WATER REUSE
SYMPOSIUM II

MUNICIPAL WASTEWATER RECLAMATION & REUSE
AND
WATER SUPPLY AUGMENTATION

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WATER RECYCLING - FUTURE RESOURCE FOR CAPE TOWN

C F Schutte
Senior Adviser
Water Research Commission
P O Box 824
Pretoria, South Africa

H G J Beekman
Chief Engineer
Cape Town Municipality
Cape Town, South Africa

ABSTRACT

The fresh water resources available to Cape Town are limited. Projections for water supply and demand indicate that the fresh water sources will all be fully committed towards the middle of the 1990's. Unconventional sources, in particular water recycling will then be relied upon to meet demands.

The current status of a project aimed at the full scale recycling of reclaimed water and future planning for the project are described.

INTRODUCTION

South Africa is a relatively dry country rapidly approaching the point of maximum utilisation of conventional water resources for the country as a whole. Projections indicate that this point could be reached soon after the turn of the century. Certain areas, however, are using their supplies to the maximum and some supplies have already had to be augmented by measures such as the interbasin transfer of water. In order to make sufficient water available in future to sustain economic and industrial growth unconventional water resources such as desalination of brackish or seawater and the recycling of reclaimed water will have to be harnessed. Water reclamation and recycling has been identified as measures which could significantly contribute to solving the water problem by relieving some of the pressure on fresh water supplies.

Research and development on water reclamation have been in progress for almost two decades in South Africa and direct recycling of reclaimed water in the municipal supply has been practised since 1969 at Windhoek to supplement the water supply. Two other areas where water recycling will have to be implemented in the near future are the Pretoria-Witwatersrand-Vereeniging Complex and the Greater Cape Town area. This paper describes the water supply-demand situation in the Cape Town area, the role which water reclamation will have to play to augment conventional supplies and the progress with and planning for the implementation of full scale water reclamation in Cape Town.

WATER SUPPLY AND DEMAND

Cape Town was founded in 1652 when the first Dutch settlers landed at the southern tip of Africa. Today the population of the Cape Town Metropolitan area is about 1,5 million with a population growth rate of about 3% per annum.

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The area has a mediterranean climate with rainfall mainly in winter and a long mainly dry summer season. The result of this rainfall pattern is an increased demand for water during the dry summer months especially for irrigation and gardening purposes and a much-reduced demand during winter. The precipitation varies considerably between mountain and flat areas, and between coastal and inland areas.(1)

The area is not heavily industrialised although a large number of smaller secondary manufacturing industries (such as textiles) as well as a small number of heavy industries do exist.

The early water supply to Cape Town was derived from springs and creeks on Table Mountain. These sources were impounded later through construc= tion of a number of smaller dams. Due to continued developments it became necessary to transport water from more distant sources from catchments to the east of Cape Town and as a result water could be supplied to local authorities en route. At present 18 local authorities and peri-urban areas receive water in bulk from Cape Town amounting to about 50% of the total volume supplies. See figure 1 for orientation.

The assured yield of currently available sources indicated in Table 1 amounts to $166x10^6m^3/a$. The current water demand is about $195x10^6m^3/a$ and is being met by temporary allocations from other sources.

The water demand of the area increased at an average rate of 6,12% per annum during the past 20 year period. This growth rate was used to project the water demand for the area for the period up to 2005 as indicated in Table II.(2)

Future projects which could be developed to meet projected demands up to 1995 include Theewaterskloof (1982), Cape Flats Aquifer and other smaller sources (1986), Palmiet River (1989). See figure 2.

LONG TERM PLANNING FOR THE RECLAMATION AND RECYCLING OF WATER IN GREATER CAPE TOWN

The conventional fresh water resources available to Cape Town will only be able to meet projected demands up to 1995. Beyond this date uncon= ventional resources such as water recycling will have to be harnessed to meet demands.

Long term planning for the reclamation and recycling of water commenced during the latter half of the 1960's when a detailed survey was carried out of the quantities and qualities of sewage flows in the area and projections were made of future flows. The main objective of these studies was to develop a master plan for

(i) the modernization of the sewerage systems and sewage purification facilities in the area,

(ii) the strategic location of sewage purification works on a regional basis,

(iii) the diversion of sewage effluents from industrial areas to a centralised purification works,

(iv) the purification of sewage effluents from essentially domestic origin at regional works and the reclamation of these effluents for reuse in future.

This master plan was accepted by the Cape Town City Council and an advanced stage of implementation has been reached.

It was subsequently decided to establish a 4500 m^3/d prototype demonstration water reclamation plant at the new Cape Flats sewage works, an activated sludge plant designed for biological nitrogen and phosphorus removal. The reclamation plant is currently under construction and will be used for developing design and operating criteria for full scale water reclamation and will also serve as a demonstration facility.

Concurrently with these developments another aspect was investigated viz the geohydrology of the coastal sand deposits of the Cape Flats area and its suitability to serve as a reservoir for the storage of reclaimed water. It was concluded from these studies that the deposits which extend to depths up to 50 m below sea level can serve as a storage reservoir.(3) However, the studies were discontinued since the aquifer is now being developd for abstraction of ground water. Once the full yield of the aquifer is realised further consideration will be given to the possible infiltration and storage of reclaimed water in the aquifer.

PRESENT STATUS OF THE WATER RECLAMATION PROJECT

The approach being followed for the eventual full scale implementation of water recycling is firstly, to establish a 4500 m^3/d prototype demonstration water reclamation plant capable of producing water of potable quality. This will be followed by investigations concerning all aspects related to recycling of water for municipal and possibly irrigation use.

The plant is currently under construction and it is expected to be completed early in 1982. The plant comprises the treatment processes required to produce reclaimed water of potable quality, i.e. chemical clarification, filtration, breakpoint chlorination, active carbon adsorption and final chlorination. Pilot scale studies to investigate the effect of ozonation and chlorination on the performance of activated carbon and on reclaimed water quality are in progress. The findings of these investigations will determine if, and where ozonation will be included in the process configuration.

Provision is also made for investigating the application of small scale reverse osmosis units to treat a side stream of final reclaimed water as well as other process streams in order to assess the potential role of reverse osmosis as substitute to some of the "conventional" reclamation processes. A separate project on the pretreatment of secondary sewage effluents for reclamation by reverse osmosis is being conducted in parallel with the aforementioned investigations.

RESEARCH AND DEMONSTRATION PROGRAM

Optimisation

A program of commissioning and optimization of the various unit processes will start after completion of construction of the plant. It is expected that these optimization studies and related research will be completed towards the end of 1984. During this period performance will be monitored as fully as possible with special emphasis on analysis and removal of residual organic material in reclaimed water and mutagenic/carcinogenic testing of concentrates of feed and final water as well as certain process streams.

Experience gained at the Windhoek water reclamation plant as well as the Stander reclamation plant in Pretoria indicate that no real problems should be experienced with optimization. However, it is realised that the characteristics of the secondary effluent to be reclaimed are somewhat different to those at the other locations mentioned and a sufficient period is therefore allowed to eliminate any possible problems which could arise.

The following will form the basis of the optimization program : maximum removal of turbidity, phosphorus and nitrogenous compounds, chemical oxygen demand, total organic chlorine, total organic halogens, volatile halogenated hydrocarbons, specific toxic compounds, micro-organisms and viruses, identification (and removal if necessary) of currently unknown compounds present at undesirable concentrations in the inflow.

Research and Development

During the optimisation stage some peripheral research will also be conducted. One aspect of importance is the possible application of reverse osmosis to replace some of the "conventional" reclamation processes with the added benefit of producing a desalinated product water. An earlier investigation aimed specifically at the application of reverse osmosis for water reclamation indicated that an excellent product could be produced but problems were experienced with reduced fluxes due to membrane fouling.

Evaluation of plant performance under production conditions

Once the plant has been fully optimised a continuous run will follow for a period of about one year, to test the performance and reliability of the plant under practical production conditions. This opportunity will also be used for demonstration purposes as part of a local and national public information programme to inform the public of the water supply-demand situation and the potential of water recycling to augment supplies.

Reuse

The stage will then be set for a final decision on the application of the reclaimed water from the prototype demonstration plant. The feasibility to recycle the 4500 m^3/d of potable reclaimed water at a very high dilution ratio in the municipal supply for direct reuse will be considered.

Advantages of an extended demonstration run will be that a facility operating under real conditions will be available for training of operators for a future large scale plant.

Figure 3 gives a time schedule for the different aspects of the program aimed at the full scale implementation of water reclamation and recycling.

PUBLIC HEALTH ASPECTS RELATED TO THE RECYCLING OF WATER IN THE MUNICIPAL SUPPLY

High priority is being given to the development of criteria for drinking water derived from polluted sources all over the world. This view was also expressed at the Airlee workshop : Protocol development : Criteria and standards for potable reuse and feasible alternatives. In South Africa the Department of Health, Welfare and Pensions is in the process of developing a set of requirements and criteria for the recycling of water in the municipal supply and these criteria are expected to be made known in 1982. These criteria are being formulated on the experience gained at the Windhoek and Stander water reclamation plants over a period of about a decade of operation, surveillance and research.

In addition to all the safety measures incorporated in a reclamation project for unrestricted reuse it is also considered essential that epidemiological studies be conducted on a population receiving reclaimed water in order to be able to identify any possible change in health patterns. Therefore, in view of the fact that reclaimed water might be introduced in the Cape Town municipal supply in the future it was de= cided to start with an epidemiological survey well before the possible introduction of reclaimed water so as to establish the background health patterns for future reference. A separate paper on this project will be presented later at this conference.

CONSIDERATION OF THE VARIOUS REUSE OPTIONS FOR CAPE TOWN

Generally speaking there are four possibilities for recycling reclaimed water. These are

Direct Recycling of Reclaimed Water in the Municipal Supply for Unrestricted Reuse

Direct recycling of reclaimed water for unrestricted use comprises the reclamation of water from secondary treated effluents to full potable quality and direct introduction into the municipal supply in admixture with other water. Direct recycling will be a feasible proposition for the reuse of relatively large volumes of reclaimed water. Demand for municipal supplies are ever increasing and additional supplies must continuously be found. Reclaimed water is a source that will always be available to satisfy part of increases in demand.

From a reticulation point of view there are a number of advantages in recycling of reclaimed water in the municipal supply viz pumping costs are kept to a minimum, evaporation losses of reclaimed water are minimized, no separate reticulation system is required. On the other hand greater care must be taken with the reclamation process and more safety barriers and greater reliability must be provided in comparison to conventional water treatment.

From an economic and practical engineering point of view direct recyc= ling seems to be the most feasible reuse option for Cape Town and research has therefore been directed mainly at this route for recycling.

Simulated Indirect Reuse

The term "simulated indirect reuse" is used for the planned return of reclaimed water to a water body which is being used as a water supply source. All the water supply sources for the Cape Town area are sur= face dams and impoundments and the larger of these serve as sources for both municipal and irrigation waters. In returning reclaimed water to such a source it might be possible to get a bigger allocation for municipal use from the source. As far as Cape Town is concerned the distances to water supply dams and the altitudes at which they are located will not favour this mode of reuse, purely on economic con= siderations.

Another possibility for simulated indirect reuse is to return the reclaimed water to the Cape Flats aquifer (4). This aquifer with an estimated yield of about $18 \times 10^6 m^3/a$ will be developed for implementation towards 1986 (5). Once the yield of this source is fully utilised further consideration might be given to supplementing the ground water by infiltration of reclaimed water if found to be economically feasible.

Industrial Reuse

A survey was carried out during 1978 to assess the potential market for an industrial grade reclaimed water in the Greater Cape Town area (6). The total potential market was found to be about $7 \times 10^6 m^3/a$ which is less than 5% of the total water usage in the area. In addition, the points of reuse are scattered over a large area making the distribution of reclaimed water very difficult and costly.

From these findings it was concluded that industrial reuse will not be a feasible proposition if large volumes of reclaimed water are to be reused.

A notable exception as far as industrial reuse is concerned is the Athlone power station which is using treated effluent from the Athlone Sewage Works as cooling water. The average volume used is about $3{,}5 \times 10^6 m^3/a$.

Irrigation Reuse

Substantial volumes of water are allocated for irrigation purposes in the Western Cape. Consequently the use of reclaimed water as a substitute for fresh water which could then be made available for municipal supplies seems to be a feasible reuse option. The various factors which should be considered in this regard include aspects such as the effects of relatively high total dissolved solids (TDS) on production and soil conditions, the cost of reclamation and pumping of reclaimed water to irrigation areas and the acceptance by farmers of reclaimed water to substitute fresh water.

The feasibility of this reuse route as an alternative option for the use of reclaimed water will receive further attention.

CONCLUSION

The fresh water resources available to Cape Town are limited. Projections of water demand indicate that these resources will be fully committed towards the middle of the 1990's. Resort will then have to be taken to unconventional resources to meet further increases in demand. Reclamation of water for recycling in the municipal supply could play an important role in this regard.

The successful divertion of industrial effluents from sewage of domestic origin and the construction of modern regional sewage purification works are important achievements in the long term planning for full scale water recycling. The operation of the prototype demonstration water reclamation plant will be the final and perhaps most important stage in the development of this future water resource for Cape Town

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Table I. Water Sources for Cape Town Supply Area

Source	Assured yield $x10^6 m^3/a$
Dams on Table Mountain	5
Steenbras Dam	38
Wemmershoek Dam	46
Voëlvlei Dam	67
Wellington (local sources)	1
Paarl (local sources)	1
Stellenbosch (local sources)	6
Strand (local sources)	2
	166

Table II. Projected Water Demand for Cape Town Supply Area

Year	Projected demand $x10^6 m^3/a$
1985	260
1990	350
1995	470
2000	632
2005	851

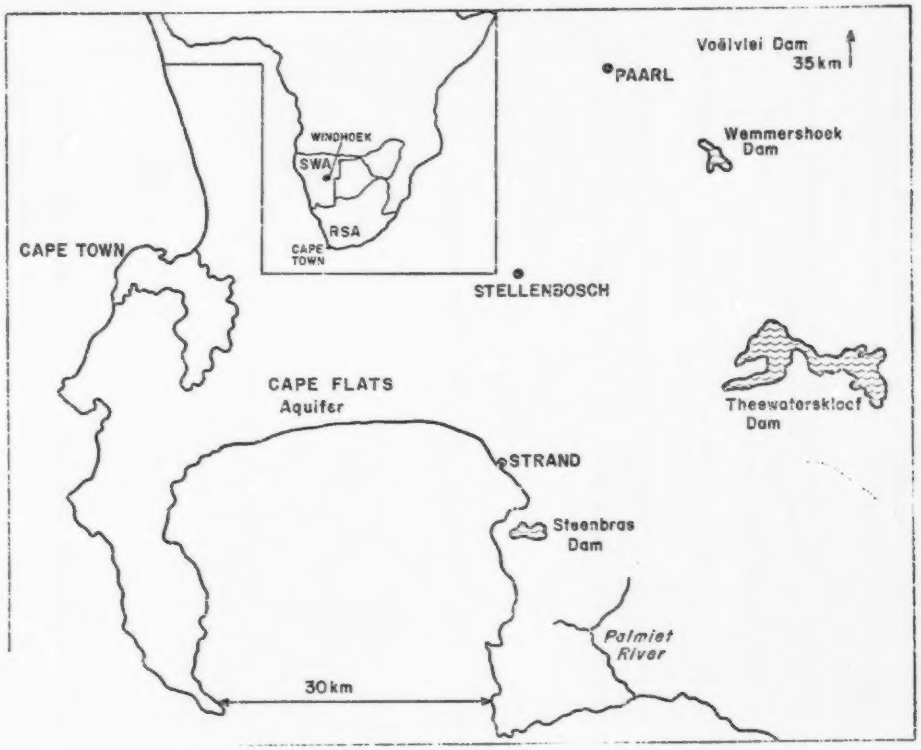
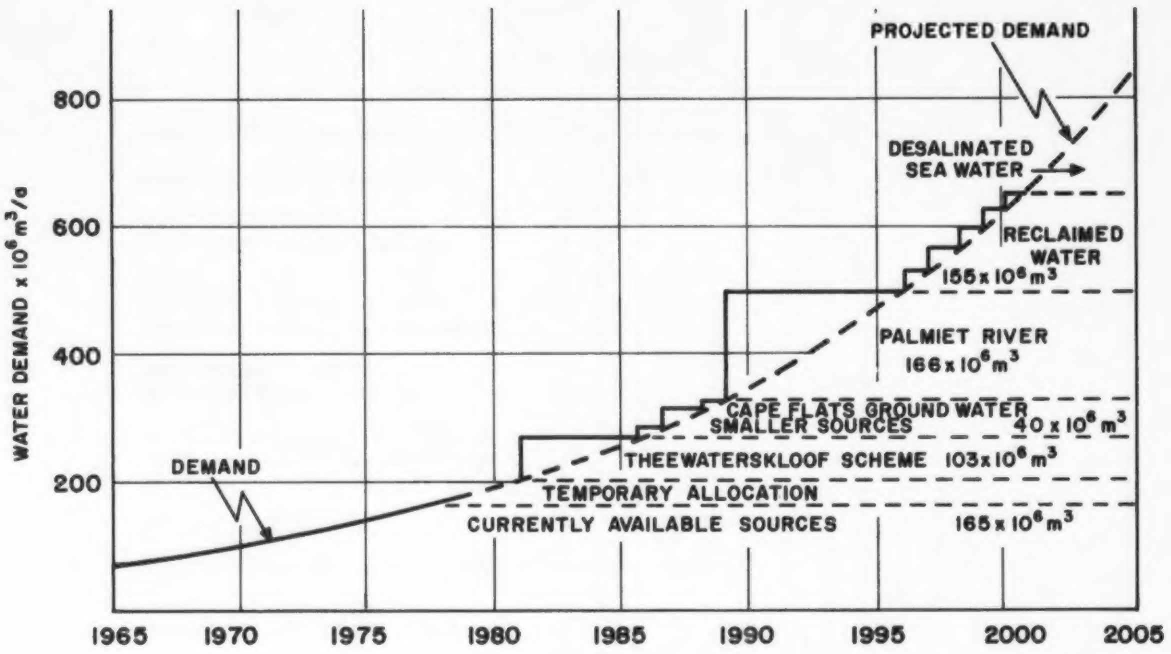

CAPE TOWN
WINDHOEK
SWA
RSA
CAPE TOWN
PAARL
Voëlvlei Dam
35km
Wemmershoek Dam
STELLENBOSCH
CAPE FLATS
Aquifer
Theewaterskloof Dam
STRAND
Steenbras Dam
Palmiet River
30km

Figure 1



WATER DEMAND AND PROPOSED DEVELOPMENT OF WATER SOURCES FOR GREATER CAPE TOWN
Figure 2

POSSIBLE TIME SCHEDULE FOR THE IMPLEMENTATION OF FULL SCALE RECYCLING OF RECLAIMED WATER IN CAPE TOWN

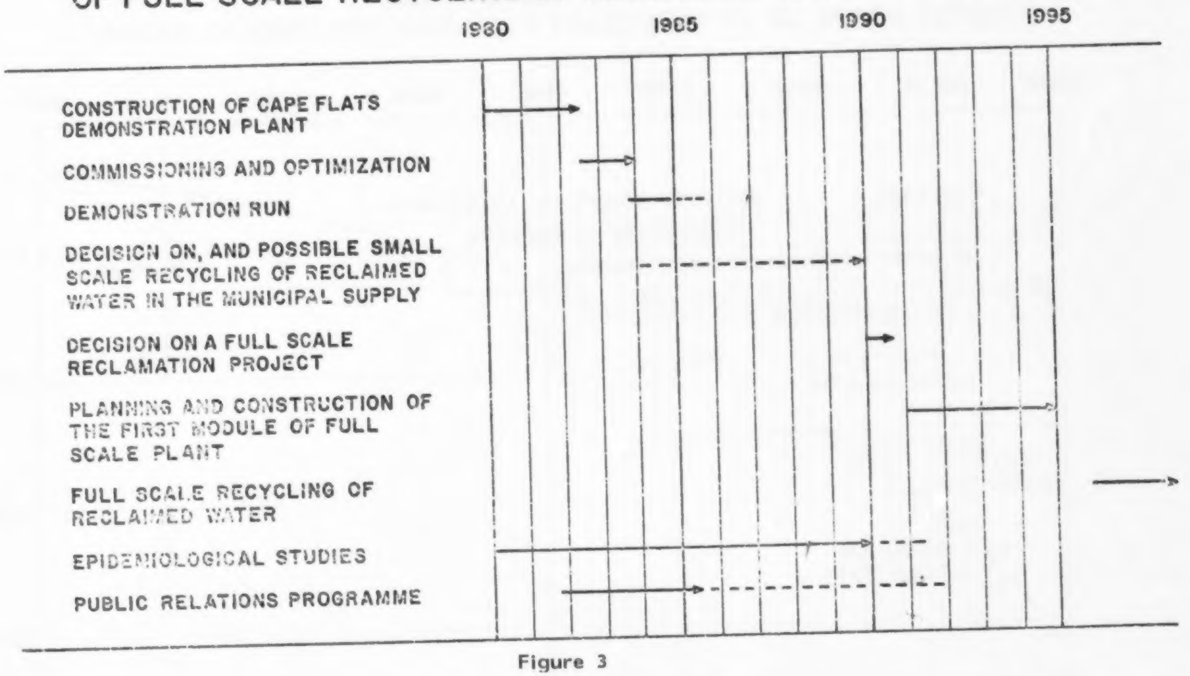


Figure 3

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RELIABILITY AND PERFORMANCE
OF
CONVENTIONAL POLLUTANT REMOVAL
CEDAR CREEK WATER RECLAMATION FACILITY
NASSAU COUNTY, NEW YORK

Raymond J. Avendt, Ph.D., P.E.
Manager Environmental Engineering Division
Greenhorne & O'Mara, Inc.
6715 Kenilworth Avenue
Riverdale, Maryland 20840

James A. Oliva, P.E.
Sanitary Engineer IV
Nassau County Department of Public Works
1 West Street
Mineola, New York 11501

INTRODUCTION

This paper discusses the first fifteen (15) months operation of the Cedar Creek Water Reclamation Facility located in Nassau County, New York. This facility is part of a wastewater reclamation and groundwater recharge demonstration project funded by Nassau County, New York Department of Environmental Conservation and the U.S. E.P.A. The facility is the result of 201 and 208 planning for Long Island that indicated the potable groundwater supply could be augmented with reclaimed water. This project, initiated in 1971, represents the commitment of over 30 million dollars for capital and operations costs and should be completed in 1984.

WATER RECLAMATION GROUNDWATER RECHARGE FACILITY

The water reclamation - groundwater recharge facility consists of three (3) parts: (1) the 5.5 mgd water reclamation facility at the site of the Cedar Creek Wastewater Treatment Plant; (2) a six and a quarter mile long, 24" diameter transmission line between the plant and the upland site of recharge operations and; (3) the groundwater recharge facility using shallow injection wells and spreading basins. At this time, all construction activity is essentially complete, operation of the water reclamation facility is on-going and backround groundwater testing is being performed prior to initiating recharge operations.

The operations data presented here is also being used to finalize the required discharge permit prior to authorizing recharge. Regulatory actions on the part of local, State and Federal agencies has been very cautious due to the groundwaters of Long Island being designated a sole source aquifer. Table 1 lists the design effluent quality standards for the reclamation facility. Additional standards for trace organics and priority pollutants are being finalized.

1. Water Reclamation Facility

The design approach taken for the 5.5 mgd water reclamation facility incorporated the best available demonstrated technology with maximum utilization of the existing plant facilities to insure consistent

Table No. 1
Water Quality Standards For Cedar Creek Reclamation-Recharge Project

Constituent or Characteristic	Desired Limit mg/1	Constituent or Characteristic	Desired Limit mg/1
ABS	0.5 mg/1	Microbiological	
Aluminum	0.1	Coliform·Org.	4/100 ml.
Arsenic	0.05		max.
Barium	1.0		1/100 ml.
BOD_5	2.0		avg.
Boron	1.0		
Cadmium	0.01		
Calcium	<Sat. Con	Pesticides	
CCE	0.2	Aldrin	0.017
Chloride	250	Chlordane	0.003
Chlorine Res. (Free)	1.0	DDT	0.042
Chromium (hexavalent)	0.05	Dieldrin	0.017
Copper	0.2	Endrin	0.001
Cyanide	0.1	Heptachlor	0.018
Fluoride	1.5		
Iron & Manganese		Hep. Epoxide	0.018
Combined	<0.3	Herbicides	0.1
Lead	0.05	Methoxychlor	0.035
Mercury	0.005	Org. PO_4 + Carbamates	0.1
Nitrogen, Total	3.0	Toxaphene	0.005
O_2Consumed	2.0		
Phenols	0.001		
Phosphorus	0.1	Physical	
Selenium	0.01	Color	15 units
Silver	0.05	TON	3 units
Sodium	50%of	TDS	500
	Cations or	Turbidity	0.5 J.T.U.
	20 mg/1	Entrained Air	None
Sulfate	250	SS	1.0
TOC	3.0	pH	6.5-8.5
Uranyl Ion	5.0		units
Zinc	0.3		

production of the high quality effluent required for recharge. Sufficient operational flexibility was provided to enable optimization of operation and control parameters. The facility has continuous automated monitoring and alarm systems, an emergency power supply, short term retention of the reclaimed water, ocean outfall disposal as an alternative, a full complement of standby equipment, and multiple units.

The water reclamation facility is shown in overall schematic in Figure 1. Design data and operating parameters are listed in Table 2. The water reclamation processes used include chemically aided primary sedimentation, two or three stage biological treatment, filtration, carbon adsorption, chlorination and storage.

Chemically Aided Primary Treatment

The primary treatment system employs addition of lime followed by primary sedimentation at pH 9.5. This increases removal of phosphorus, BOD_5, suspended solids and heavy metals, thereby optimizing and protecting the biological nitrification system.

The influent flow to the water reclamation plant is screened and degritted wastewater withdrawn under controlled conditions from the existing plant primary influent flow. The wastewater is conveyed to chemical treatment facilities. Contained in the chemical treatment facilities are a rapid mix tank for dispersal of the lime, automatic lime slaking and feeding equipment, a slurry tank and the required control and monitoring devices. The lime mixed effluent from the rapid mix tank is discharged by gravity to two flocculation chambers. In each of the chambers a horizontal shaft slow speed mixer is installed for flocculation. The flocculated effluent then flows to one of two primary tanks that are used in the reclamation process.

Two Stage Biological Treatment System

The secondary treatment system has been designed to promote biological nitrogen removal in conjunction with oxidation of the remaining carbonaceous material. The design allows for the operation of the secondary system as a two stage suspended growth system, with combined carbon oxidation-nitrification, intermediate clarification, denitrification, post aeration-stabilization and final clarification. The settled wastewater from the primary tank flows by gravity to existing aeration tanks. A portion of the existing aeration tanks provides a detention time of 5.9 hours based on the design flow rate. From the combined carbon oxidation-nitrification tank the mixed liquor enters one existing 100 foot diameter final clarifier is returned to the carbon oxidation-nitrification tank, utilizing the existing return sludge well, pumps, meters and lines. The nitrified effluent from the intermediate clarifier passes to the denitrification tank which provides detention time of two hours. Methanol is added to the tank influent flow at a controlled rate as a supplemental organic carbon source in the denitrification process.

The denitrified liquor flows to a post aeration-stabilization tank. The purpose of the post aeration-stabilization tank is to remove any supersaturated nitrogen gas, to avoid rising sludge problems in the final clarifier, to provide a mixing zone for the addition of alum and/or polymer for further phosphorus removal, and to provide an additional aeration period for the removal of excess methanol. The aerated liquor is conveyed to an existing clarifier for final clarification.

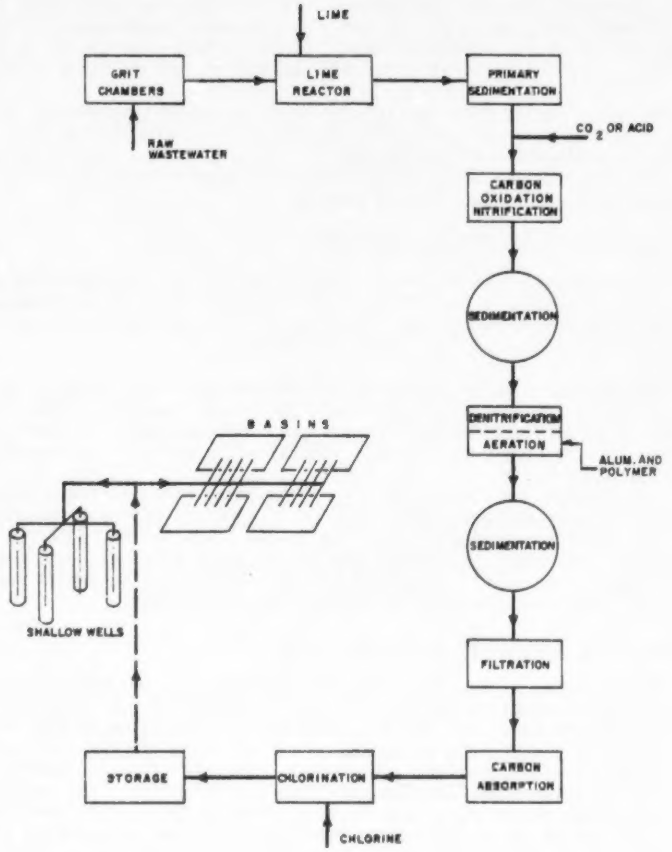

LIME
GRIT CHAMBERS
LIME REACTOR
PRIMARY SEDIMENTATION
RAW WASTEWATER
CO 2 OR ACID
CARBON OXIDATION NITRIFICATION
SEDIMENTATION
DENITRIFICATION
AERATION
ALUM. AND POLYMER
SEDIMENTATION
FILTRATION
CARBON ABSORPTION
CHLORINATION
CHLORINE
STORAGE
BASINS
SHALLOW WELLS

FIGURE 1

SCHEMATIC DIAGRAM OF WATER RECLAMATION-RECHARGE FACILITIES

Table No. 2
Design Data

Incoming Flow Characteristics	
Flow, mgd	5.5
Suspended Solids, mg/l	240
Biochemical Oxygen Demand (5-Day), mg/l	220
TKN, mg/l	35
NH_3-N, mg/l	22
Total Phosphorus, mg/l	16
Lime Treatment System	
Lime Reactor Volume, gal	4,190
Detention Time, min	1
Lime Dose, mg/l	200 to 350
Flocculation Chamber*	
Number of Chambers	2
Detention Time/Chamber, min	6.25
Number of Horizontal Shaft, Slow Speed Mixers	2
Diameter of Paddle Assembly, ft	4
Primary Tank*	
Surface Loading Rate, gpd/sq.ft	830
Weir Overflow Rate, gal/ft/day	11,000
Detention Time, hr	2.1
Combined Carbon Oxidation-Nitrification*	
Tank Volume, cu.ft	180,000
Detention Time, hr	5.9
MLVSS, mg/l	2,700
F/M	0.15
Sludge Age, day	17
Oxygen, scfm	11,200
Intermediate Clarifier*	
Solid Loading Rate, lb/day/sq.ft	27.5
Overflow Rate, gpd/sq.ft	700
Denitrification-Anoxic Mixed Reactor*	
Volume, cu.ft	61,300
Detention Time, hr	2
MLVSS, mg/l	2,700
Methanol, lb/day	3,240
Post Aeration-Stabilization	
Volume, cu.ft	30,650
Detention Time, hr	1
MLVSS, mg/l	2,700
Oxygen, lb/day	2,140
Alum, lb/day	3,030

Table No. 2 (Continued)

Final Clarifier*	
Solids Loading Rate, lb/day/sq.ft	36
Overflow Rate, gpd/sq.ft	700
Recycle	0.5Q
Filtration	
Number of Units	2 (+ 2 standby =4)
Unit Size	13.3' x 38.7'
Filter Media	Dual Media (Sand, Anthracite)
Filtration Rate, gpm/sq.ft	3.75
Backwash Rate, gpm/sq.ft	15 to 20
Carbon Adsorption System	
Number of Units	2 (+2 standby=4)
Unit Size, ft	13.3' x 38.3'
Contact Bed Depth, ft	8
Total Carbon, lb	482,800
Unit Loading Rate, gpm/sq.ft	3.75
Detention Time, min	16 (2 Units in parallel)
Backwash Rate, gpm/sq.ft	15 to 20
Carbon Regeneration Furnace Size	(1)-11.75' Dia. x 5' Hearth
Carbon Regeneration Furnace Area, sq.ft	450
Number of Carbon Storage Tanks	1
Carbon Storage Capacity, cu.ft	4,120
Chlorination*	
Detention Time, min	30
Chlorine Feed Rate, lb/day	350
Number of Feeders	3
Storage, Covered*, hr	9

*Existing Structure

Operational flexibility is provided to allow conversion from a two stage to a three stage biological treatment system as a fail-safe mechanism to assure the production of a high quality effluent. A three stage intermediate system would consist of a high rate activated sludge unit, separate nitrification, followed by denitrification.

Filtration and Carbon Adsorption

The filtration and carbon adsorption system design is based on the use of multiple individual units, the size of which can be incorporated directly into a future fullscale Nassau County recharge system.

The clarified effluent from the secondary system is pumped under controlled conditions to automatically backwashed, dual-media filters. Two gravity type filters are provided with two additional filters on standby. Each filter provides a surface area of 515 square feet and operates at under 4 gpm/ft^2.

The carbon adsorption facilities consist of two contacter units in parallel, with two standby units provided. Each unit provides 515 square feet of surface area. The adsorption units are operated as downflow packed bed units, 8 feet deep. Contact time is approximately 16 minutes.

Chlorination and Storage

Two unused aeration tanks providing 9 hours detention time were covered and serve as the chlorine contact chamber and storage tank. The storage tank also serves as a pump suction chamber for high head pumps to deliver treated water to the recharge site and provides the necessary equalization to permit continuous delivery of 4.0 mgd to the injection wells, despite fluctuations in plant output due to backwashing of filters and carbon adsorbors.

2. Transmission Main System

The demonstration project involves the use of a 24 inch diameter concrete pipe transmission main to convey reclaimed water the Meadowbrook recharge site. The routing parallels the Wantagh State Parkway from the Cedar Creek treatment plant to the recharge site. The length of transmission main is approximately 6.25 miles.

3. Recharge Facilities

The Meadowbrook recharge site is a triangular-shaped piece of County-owned land located in the geographic center of the County. It includes approximately 60 acres of land which is occupied in part by the Nassau County Correctional Center and the former Meadowbrook Sewage Treatment Plant.

Both shallow well and basin recharge studies are to be conducted at the Meadowbrook site. The proposed program will recharge 4 mgd, with approximately 2.0 mgd recharged through basins and the remaining through wells. Five wells and eleven basins are available. The basins, each 50' x 100' will be used to determine the management practices that are most effective for optimizing recharge. Evaluation of the clogging phenomena associated with the application of reclaimed wastewater and the potential for the unsaturated zone to improve water quality will be performed. Five wells, 100' deep with 30' screens are installed at the Meadowbrook site to recharge reclaimed wastewater. Four of the wells may be in operation any specified time, with one on standby. Each well would recharge 0.5 mgd.

The Meadowbrook recharge site is surrounded by a monitoring network of 46 observations wells. They are installed near the center of both the injection well and basin recharge sites. In addition to the observation well network, an onsite reservoir is automatically monitored.

4. Operations, Performance, and Reliability

Currently, Nassau County and the U.S.G.S. are conducting comprehensive monitoring programs to characterize the reclaimed water and existing groundwater prior to recharge. The results of monitoring program for priority pollutants present in the raw wastewater and reclaimed water are not finalized. The analysis of initial data indicates that the priority pollutants are not present,or at levels not warranting concern.

To determine the performance and reliability of the water reclamation plant, the operations data for the first fifteen (15) months of operation were analyzed. An investigation of the available methods to evaluate performance data considered data plots vs. time, relative frequency plots, normal distribution plots and lognormal distribution plots. The lognormal frequency distribution plot was selected to analyze the relationships between design, operation and performance. This method allowed evaluation of performance on a probability basis with the geometric mean value approximated at the 50% probability (or median) level. When the data is in statistical control the geometric mean is a fractional value approaching the arithmetic mean.

An investigation of the available methods to evaluate the reliability of the unit processes considered plotting the standard deviation of performance data, 95% confidence intervals, R Charts, the relative standard deviation, coefficients of variation, and the Spread Factor. The Spread Factor, S , which is the antilog of the standard deviation of the logarithms of the original data on the lognormal frequency distribution plot, was selected to analyze the relationships between design, operation and the reliability of performance. Since the Spread Factor represents the slope of the log normal probability plot, the performance and reliability can be determined from the same figures.

A summary of the performance/reliability analysis is presented below for conventional pollutant removal through the reclamation plant.

BOD_5

The removal of BOD_5 across the plant averages 98%. Analysis of the spread of data indicates that the performance of the chemically aided primary sedimentation tank is quite stable (47% removal based on geometric mean values), as indicated by the low S values of 1.06 and 1.09, respectively. BOD_5 removal across the plant through biological treatment exceeds96% comparing geometric means and results in an increased spread of effluent values, S = 1.24. Carbon adsorper effluent values have a geometric mean of less than 2 mg/l with S = 3.73. It appears that the performance of the reclamation plant to remove BOD_5 is greater than anticipated. However, the higher the performance the more relative spread in the effluent values (Figure 2).

Suspended Solids

Suspended Solids (Figure 3) removal in the reclamation plant exceeds 98%. Again the chemically aided primary sedimentation tank is very stable with a 49% removal based on geometric means and equal S factors. The removals across the biological units and through filtration and adsorption are stable with S values equal to or less than 2.0.

Phosphorus

Phosphorus removal is accomplished through chemical precipitation/sedimentation and filtration. A 40% reduction is achieved on a stable basis (S = 1.18) across the chemically aided primary tanks with lime addition to pH 9.5. Overall reduction exceeds 93% (geometric means) and is relatively stable (S=2.1). See Figure 4.

Nitrogen Transformation

Oxidation of ammonia nitrogen to nitrate is accomplished in the first stage biological system. Essentially complete nitrification occurs (see Figure 5). The overall rate is 96% (geometric) and is quite stable (S = 1.25). It appears that the system is very conservatively designed and no appreciable effect of temperature is noticed. Denitrification in the second stage biological system utilizes methanol as the supplemental organic carbon source. The process removes 93% of the nitrate nitrogen producing an effluent averaging 2.1 mg/l (geometric). The denitrification system (S = 2.7) is less stable than nitrification. Methanol dosage has been kept at approximately 3.8 to 1 on a weight basis.

Chemical Oxygen Demand

Overall reduction of COD is 97% (geometric), as shown in Figure 6. Removals across the primary tanks is quite stable (S = 1.12) and averages 41% (geometric). Through the biological secondary, the reduction is just as stable (S = 1.1) and averages 92% (geometric). The final effluent spread is relatively unstable (S = 2.5) with a geometric mean value of 7 mg/l.

CONCLUSION

The results of this analysis of performance and reliability require prudent interpretation. We have found that the raw data was lognormally distributed and therefore, assume that they represent cumulative effects of the conservative design and operating parameters. The results must also be considered relevant to the range of data base values. It does not appear that any individual unit process or the reclamation facility as a whole, is being stressed. Additional testing of the reclamation facility is warranted to determine the critical limits for each unit process and the ability to recover from process failure.

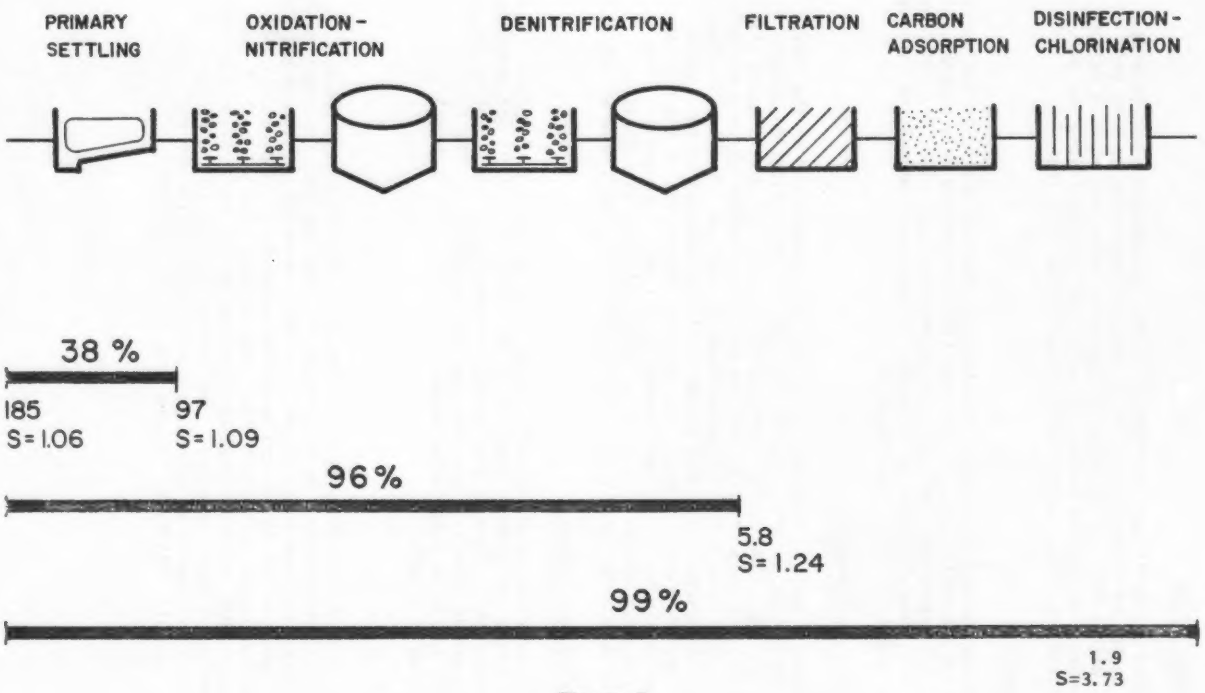

PRIMARY SETTLING
OXIDATION - NITRIFICATION
DENITRIFICATION
FILTRATION
CARBON ADSORPTION
DISINFECTION - CHLORINATION
38 %
185
S=1.06
97
S=1.09
96%
5.8
S=1.24
99%
1.9
S=3.73

Figure 2

BOD$_5$ REMOVAL

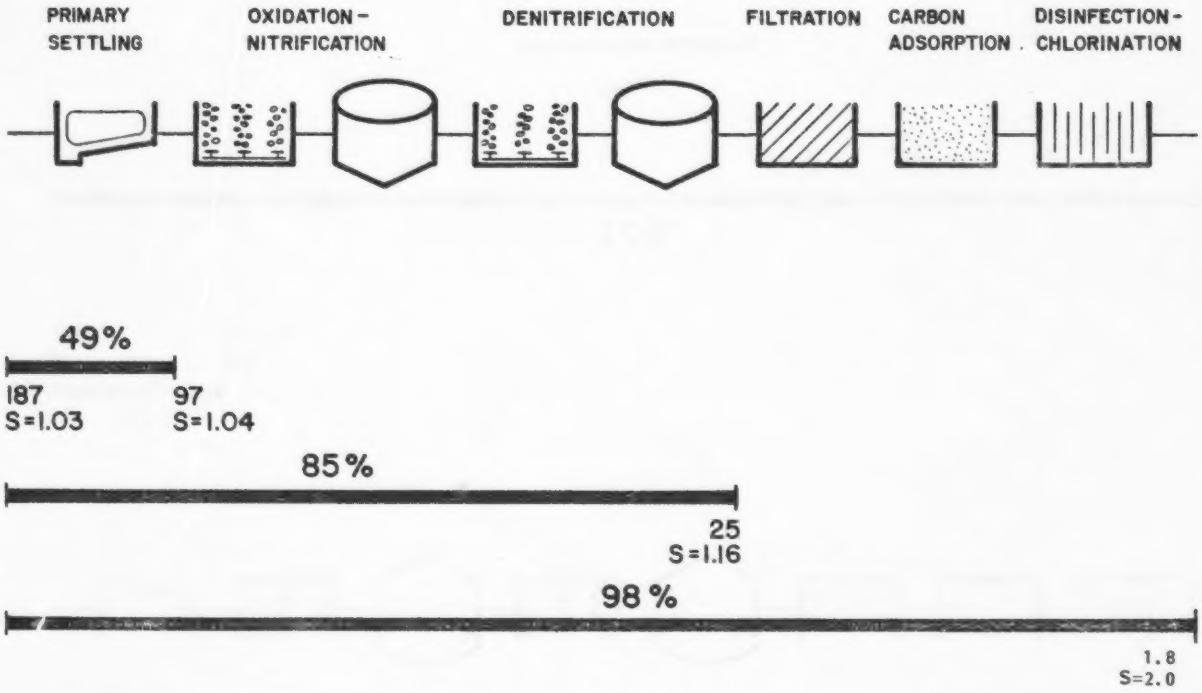

PRIMARY SETTLING
OXIDATION - NITRIFICATION
DENITRIFICATION
FILTRATION
CARBON ADSORPTION
DISINFECTION - CHLORINATION
49%
187 S=1.03
97 S=1.04
85%
25 S=1.16
98%
1.8 S=2.0

Figure 3
SUSPENDED SOLIDS REMOVAL

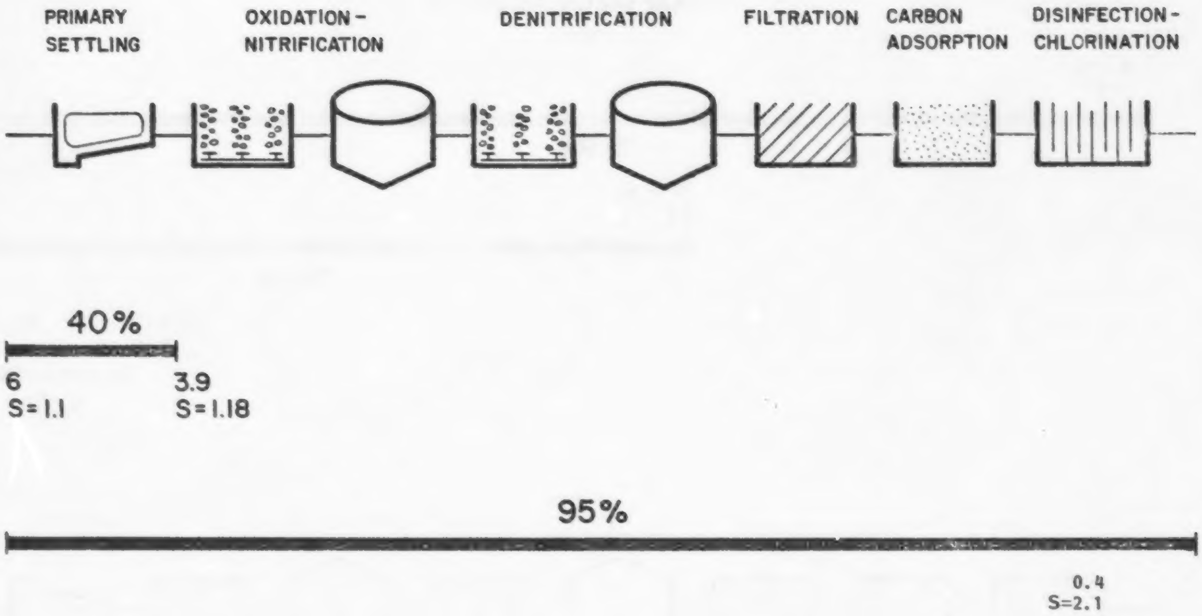
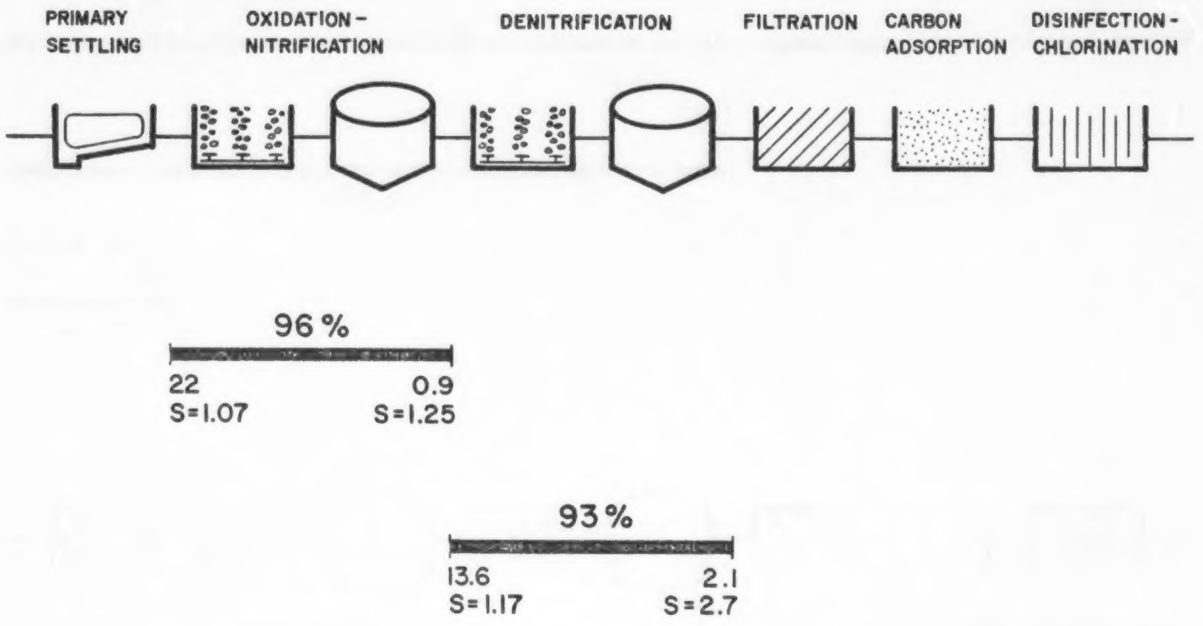

PRIMARY SETTLING
OXIDATION - NITRIFICATION
DENITRIFICATION
FILTRATION
CARBON ADSORPTION
DISINFECTION - CHLORINATION
40%
6
S=1.1
3.9
S=1.18
95%
0.4
S=2.1

Figure 4

PHOSPHORUS REMOVAL



PRIMARY SETTLING
OXIDATION - NITRIFICATION
DENITRIFICATION
FILTRATION
CARBON ADSORPTION
DISINFECTION - CHLORINATION
96 %
22
S=1.07
0.9
S=1.25
93 %
13.6
S=1.17
2.1
S=2.7

Figure 5

NITROGEN TRANSFORMATION

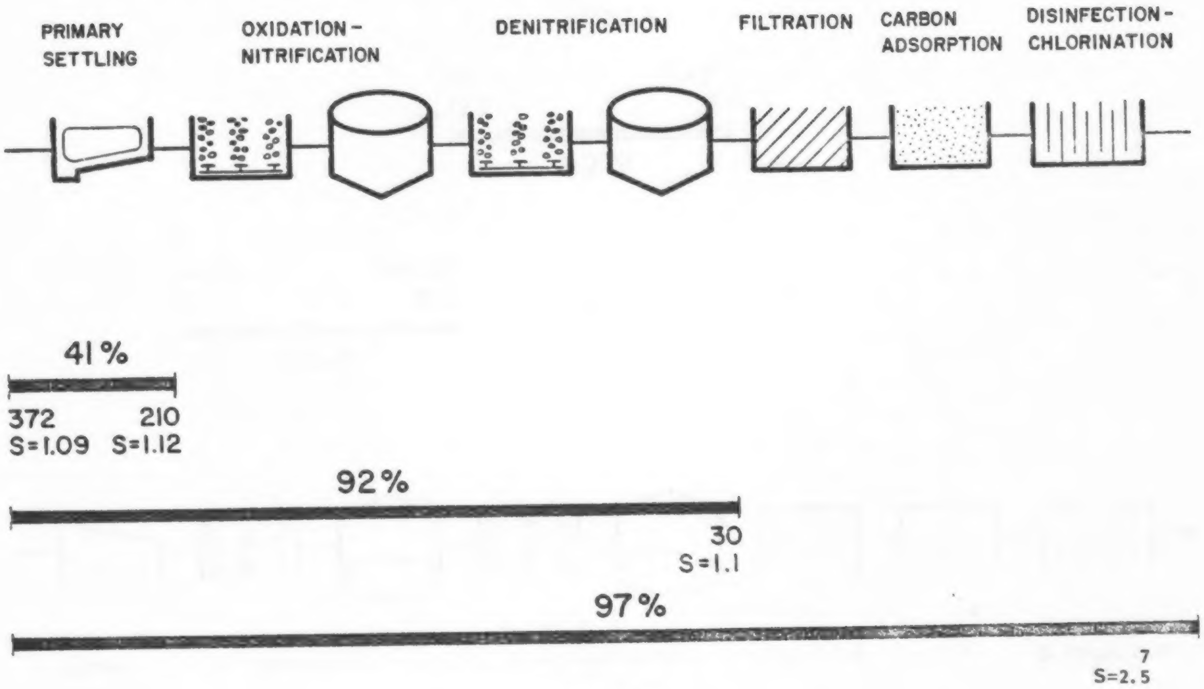

PRIMARY SETTLING
OXIDATION-NITRIFICATION
DENITRIFICATION
FILTRATION
CARBON ADSORPTION
DISINFECTION-CHLORINATION
41%
372
S=1.09
210
S=1.12
92%
30
S=1.1
97%
7
S=2.5

Figure 6
COD REMOVAL

PB82-223181

PERFORMANCE EVALUATION OF GREYWATER RECYCLE SYSTEMS

Damann L. Anderson
Specialist, Department of Civil and Environmental Engineering
University of Wisconsin-Madison

Robert L. Siegrist, P.E.
Specialist, Department of Civil and Environmental Engineering
University of Wisconsin-Madison

William C. Boyle, Ph.D., P.E.
Professor, Department of Civil and Environmental Engineering
University of Wisconsin-Madison

INTRODUCTION

Traditional approaches to water resource management have given little consideration to the cautious, non-wasteful use of water. As water demands and waste flows increased, new sources of supply were developed and water and wastewater facilities were expanded. For the most part, water conservation and wastewater reclamation were viewed as eccentric strategies, appropriate for only a few isolated areas or occasions. However, the need for these alternative approaches as part of an overall water resource management strategy has gained increased recognition during the past five years as concerns over U.S. water resources have grown [1-2].

A significant portion of the nation's consumptive water use and concommitant wastewater flow results from domestic activities. As of 1975, domestic uses accounted for over 40% of the water use that produced waste flow requiring subsequent treatment [3]. In residential dwellings, various in-home activities contribute to an annual per capita consumption of potable water in excess of 69,000 L [4]. Of this, over 75% results from toilet usage, bathing and clotheswashing, with over one-third due to toilet usage alone. For the average American, yearly toilet flushing results in the contamination of nearly 23,000 L of fresh potable water to transport a mere 490 L of body waste. Serious questions have been raised regarding the need for water of potable quality to perform various domestic functions. Onsite recycling of residential wastewater has been suggested as a strategy to provide water of a suitable quality for the intended use, while reducing potable water demands and wastewater loadings. Since the performance requirements of any recycle system are governed by the influent wastewater characteristics and the intended reuse activity, major emphasis in onsite home recycling has been directed toward reclamation of the greywaters (non-toilet wastes), for reuse in non-body contact functions such as toilet flushing and lawn irrigation. The purpose of this paper is to provide an evaluation of the performance of these home greywater recycle systems. This assessment is based upon a review of the literature as well as a demonstration study conducted at the University of Wisconsin.

LITERATURE SUMMARY

One of the first and most comprehensive investigations into the feasibility of household wastewater reuse was reported by Bailey et.al [5]. This study analyzed the feasibility of four different household reuse schemes: (1) reuse of all wastewater for all uses except drinking; (2) reuse of non-sanitary wastes for toilet flushing and laundering; (3)

aerobic treatment of all wastewater for lawn watering; and, (4) reuse of greywaters (bath, shower, clotheswasher), for toilet flushing. Treatment requirements were suggested for each reuse scheme based on a water quality required as a function of the intended use. Although all schemes appeared to be technically feasible, results of the study indicated that the only reuse scheme which even approached potential cost-effectiveness was the reuse of greywaters for toilet flushing. Prohibitive costs arose in the other three reuse schemes because of the treatment required prior to reuse. Bailey, et.al., projected a 39% reduction in wastewater flow from an "average" home which recycled washwater for toilet flushing.

Other investigations into the feasibility of onsite recycling have reported similar projections and have agreed with the practicality of recycling greywaters or washwaters for non-body contact functions such as toilet flushing and lawn irrigation [6-11].

Studies that actually demonstrated residential greywater reuse have been few and somewhat limited. A summary of the more comprehensive studies is given in Table 1. The studies by McLaughlin [12], and Cohen and Wallman [13], were the most complete and yielded similar results with respect to flow reduction and system performance. Based on the results of these investigations (Table 1), greywater reuse was shown to be technically feasible and a disinfection process and routine system maintenance were identified as essential for effective recycle system performance. While significant water savings and waste flow reductions were realized, home recycle systems were assessed as economically attractive only under extreme water cost or wastewater disposal conditions, and then only in reuse for non-body contact functions such as toilet flushing and lawn irrigation.

The greywater recycle systems evaluated in previous studies were generally prototypes or "owner built" systems, and much experimentation by the investigators accompanied their use. More recently, a number of proprietary systems have become available or are under various stages of development. To provide performance information about the systems, the National Sanitation Foundation (NSF), has recently adopted standards and laboratory testing procedures for commercially manufactured wastewater recycle/reuse systems [17]. Systems are tested by NSF at the manufacturer's request and must meet standards for design, construction and performance during a laboratory test. Thus far, no results from tests of greywater recycle systems have been published by NSF.

UNIVERSITY OF WISCONSIN DEMONSTRATION PROJECT

To enhance the existing data base, a field study was initiated at the University of Wisconsin in the Fall of 1978 under sponsorship of the U.S. Office of Water Research & Technology and the State of Wisconsin. The objectives of the study were to identify residential greywater recycle systems being commercially manufactured and to evaluate the systems under actual residential usage. This evaluation was to determine the magnitude of water savings and waste flow reductions achieved; delineate system installation, operation and maintenance requirements; characterize the water quality of various waste streams and the recycle water; identify the potential for long-term user acceptance; determine potential health concerns; and estimate system costs. The methods and results of this investigation have been documented elsewhere [18], and only a brief synopsis is presented herein.

Methods

At the onset, a search was made to identify commercially available home greywater recycle systems. Three systems that purified bathing and laundry washwaters for reuse in toilet flushing were initially selected for study (Table 2), but only the Aquasaver system [19], proved to be truly available. This system employed the unit processes of sedimentation, pressure cartridge filtration (20 µ), and chlorine disinfection in a small inhouse module (Fig. 1-2). Two Aquasaver units were installed in two homes and monitoring of their performance occurred over a total of 647 days. Volumetric flow data were collected automatically for interior water use, toilet water use, makeup water use and unit overflow water using specially altered water meters and flow indicating switches interfaced with occurrence counters and continuous strip-chart recorders. In addition, toilet fixture use data was also automatically monitored. Data were collected at each home over many multi-day periods and analyzed on an hourly and daily basis. System operations were monitored with separate power meters and elapsed time indicators, and maintenance requirements were delineated in a log. User acceptance was assessed through recordings in a user log and responses to a final questionnaire. Qualitative characterization was also accomplished through collection of grab and 24-hour flow composited samples with analyses for various parameters performed according to Standard Methods [20].

Results

Water Use and Wastewater Flow. The inhouse water use and waste flow characteristics measured at the two homes with the recycle systems in use are summarized in Table 3. The average daily freshwater flow was 78.0 and 126.7 Lpcd (Table 3). It should be noted that the residence with lower use also possessed conventional water saving faucets and showerheads with flow rates of 8 to 12 Lpm. Day to day variation, shown by the limits of the 95% confidence interval for daily flow expressed as a percent of the mean day, were 75 to 125% and 89 to 111%. Since toilet water use was recycled washwater, freshwater use for flushing was essentially eliminated as long as washwater production and storage met toilet flushing demands. At home NE no additional freshwater was needed for flushing, while at home VAR an average of 2.3 Lpcd was required. This was due to occasional unfavorable balances between available washwater and required flushwater, as well as to a slight difference in recycle system design requiring freshwater for chlorine feed with each use. The maximum daily freshwater flow at the two homes was 280 Lpcd and 364 Lpcd (Table 3). Hourly water use data indicated wide fluctuations with minimum flows of zero and maximum flows of 68.1 and 113.6 Lpch. Maximum day and hour flows were due almost entirely to non-toilet water use at these sites. Assessing the impacts of water-saving technologies on the water use characteristics at a given home can be a complex task. At first glance, the most direct method would appear to be a comparison of data obtained prior to installation of the water-saving technologies to post-installation data. However, this approach suffers from several potentially serious shortcomings. For new homes this comparison is impossible. At existing homes, changes in water demand and fixture usage totally unrelated to the water-saving technologies employed can yield inaccurate results. These changes in water use can be due to rapidly changing lifestyles of growing children, changing work schedules and lifestyles of adult residents, and changes in the physical characteristics of the dwelling including water-using fixtures, water supply pressure, and so forth.

For these reasons, an alternative strategy was used to evaluate the impact of the water recycle system. The measured fixture usage data was utilized to determine the water use characteristics that would have occurred if conventional toilet systems had been used instead of the recycle systems. The results of this analysis showed that the use of the recycle systems resulted in reductions of 24 and 35 Lpcd compared to a 13.2 L toilet and 36 and 50 Lpcd compared to a 18.9 L toilet. (Table 4). These reductions represented 24 and 22%, and 31 and 28% reductions in total daily freshwater flow, respectively, and compared closely to the results of previous demonstrations of greywater recycling (Table 1). Day-to-day variations in freshwater use were not significantly altered. The maximum days were reduced by 7 to 16% while the maximum hourly flows were not changed.

Water Quality. The quality characteristics of various process streams associated with the recycle system are shown in Tables 5 and 6. Appreciable amounts of pollutants were found in the raw greywater, confirming the results reported by previous investigators [14, 15, 21]. The recycle water quality varied widely and was generally of a much lower quality than a typical freshwater toilet supply. Variations in coliform bacteria concentrations in the recycle water corresponded closely to variations in residual chlorine levels. As long as a measurable chlorine residual was present, total and fecal coliform values were <10 org./100 mL.

Only limited pollutant removals were achieved by the recycle system. At home NE, pollutant reductions ranged from 0 to 70%. The increase in total solids from raw to recycle was expected due to the addition of calcium hypochlorite in the disinfection process. Results at home VAR revealed increases in many pollutant levels. The reason for this was not clear, but day-to-day variability in the raw washwater and attenuation in the storage tank may have been responsible. At both homes, 20 µ pressure cartridge filtration afforded minimal pollutant removals, with the bulk of any renovation occurring as a result of the sedimentation and disinfection processes.

The quality of the recycled water is important for health, safety and operational considerations. Presently, no regulatory standards exist regarding recycle water quality for home toilet flushing and lawn irrigation [22]. NSF Standard 41 [17], has set recycle water quality standards for systems approved by their test laboratory, but at present no home greywater recycle system has been approved under this standard. The Aquasaver system was tested by NSF under laboratory conditions before adoption of Standard 41 and was approved under NSF Basic Criteria C-9. The recycle water quality values required by Basic Criteria C-9 and Standard 41 are listed in Table 7. Based on the results of this study, under field conditions, the Aquasaver recycle water met NSF Standard 41 limits, except BOD_5 at both homes and TSS at home VAR.

Water quality criteria for landscape irrigation have been suggested by Culp et.al [23], as shown in Table 8. Comparison of the recycle water quality data to these criteria revealed that the recycle water was of marginal quality for lawn irrigation in terms of BOD_5, dissolved and suspended solids and coliform bacteria. In addition, the occasional high chlorine residuals could cause turf bleaching and discoloration.

System Installation. Installation of the Aquasaver recycle system can be readily accomplished in a new dwelling. Additional plumbing requirements over a conventionally plumbed house include separate toilet supply lines, washwater drain lines, and recycle system vents and connections. Retrofitting such a system is very site specific, and can pose substantial difficulties due to venting requirements and the need for separate toilet supply lines, especially in two-story houses with second floor bathroom facilities.

Operation and Maintenance. The only major operational problem encountered with the recycle system was in maintaining a proper chlorine residual in the recycle water. Residual chlorine values fluctuated widely (0 to 25 mg/L), due to fluctuations in raw washwater quality as well as system design, and caused infrequent odor problems at both homes. Operation at a desired constant residual chlorine level would require considerable monitoring and adjustment. Chlorine use by the system was approximately 0.20 gm/L at home NE and 0.30 gm/L at home VAR in the form of calcium hypochlorite tablets of 70% available chlorine content. Power use by the recycle system was 0.021 and 0.013 kilowatt-hours/cycle at homes NE and VAR, respectively. Scheduled maintenance was performed quarterly in a total of approximately 3 man-hours and consisted of cleaning an influent screen, washing cartridge filters, replenishing chlorine tablets and removing sludge from the washwater storage tank. Results of this study indicated that the maintenance required for the washwater recycle system may vary from home to home due to differences in water use and raw washwater quality. At home NE, quarterly maintenance as described was readily accomplished and sufficient to maintain the system. In contrast, at home VAR, the influent screen and cartridge filters clogged more severely and made cleaning much more difficult. At this home more frequent maintenance with annual replacement of the cartridge filters appeared necessary. Sludge accumulations were noted at both homes and consisted of a wispy black layer occupying the bottom 2 to 10 cm of the storage tank. Analyses of several grab samples of this material revealed high concentrations of organic materials and suspended solids (Table 9). Sludge disposal via the house sewer system was felt to be the most practical scheme.

Costs. The costs to purchase, install and operate the washwater recycle system as well as a conventional toilet system are outlined in Table 10. These costs are based on those actually encountered in this study, supported by estimates from equipment manufacturers and local plumbers.

ASSESSMENT OF HOME GREYWATER RECYCLING

In the past, greywater was considered by many to be relatively innocuous, unlike a real domestic wastewater. Even today, this belief prevails in many areas. Data from characterization studies have demonstrated that greywater is indeed a wastewater which contains appreciable quantities of oxygen-demanding substances, suspended solids, nutrients and fecal organisms [14, 18, 21]. It seems reasonable that varying amounts of organic materials, solids and nutrients are routinely added to the raw greywater by soil from bathing and laundering as well as from the various consumer products used in these activities. However, the high concentrations of fecal organisms measured in this and other studies are somewhat surprising and conventional interpretation would suggest that greywater may be routinely contaminated with fecal material. To yield a measured level of 10^5 fecal coli/100 ml would require that approximately 150 mg of wet fecal material (2.7×10^9 E. coli per wet gram of human feces), were contributed daily to a greywater stream of 400 Lpd. This amount conceivably could be added via laundering and personal hygiene functions. Until proven otherwise, it seems prudent to assume that raw greywater does present a potential health hazard and the treatment system prior to reuse should address this fact.

The results of the field study and previous studies have shown that the use of a system to recycle home greywaters for toilet flushing can significantly reduce household water use and wastewater flows. Although the magnitude will vary between households, the reductions potentially achievable at "typical" American homes are outlined in Table 11. These results are based on the reuse of greywater for toilet flushing only, and higher reductions (theoretically 65% or more), could be achieved if reuse for lawn watering occurred as well. Several potential problems exist with this reuse strategy, however. In many areas of the U.S., the need for lawn watering is limited, and any additional reduction from such reuse may be negligible. This fact is supported by the very slight increases in flow reductions achieved by Cohen and Wallman [13], when reuse for both toilet flushing and lawn watering were evaluated (Table 1). Furthermore, the quality of the recycle water as measured in the field study was marginal for lawn watering compared to recent landscape irrigation criteria (Table 8).

If recycling greywaters for toilet flushing is the only reuse mode contemplated, the level of treatment required deserves careful consideration. Investigations have shown that the water standing in a normal toilet bowl between flushes often contains levels of fecal bacteria equal to or greater than those in raw greywaters [24,25]. Thus, purification to a potable water quality prior to toilet flushing reuse seems unreasonable. Minimal treatment to ensure aesthetic acceptance (odors, foaming, discolored water...), and maintenance of near-normal functioning of the toilet fixture (staining, corrosion), appear adequate. In the field evaluation, the pressure filtration process added little to the performance of the recycle system, while representing a significant part of the system cost. This result has also been reported previously [12]. Since the disinfection process proved to be the most important unit process in providing an acceptable flush water, perhaps a more cost-effective system could be designed utilizing only sedimentation and disinfection.

The proper operation of the recycle system evaluated in the field study required regular monitoring. While the operation and maintenance needs were simple, homeowners may not be willing or able to perform them regularly and poor operation could result. For this reason, strong consideration should be given to the use of maintenance contracts with plumbing contractors or other trained personel. As discussed previously, user acceptance of the greywater recycle system was both positive and negative. In general, both the field evaluation and previous studies have revealed that people are not reluctant to reuse greywaters for such non-body contact functions as toilet flushing and lawn irrigation. The main negative comments received from homeowners in the field study involved problems (odors, discolored bowl water...), caused by less than optimum system performance.

Although significant reductions in water use and wastewater flow can be obtained by a greywater reuse system, the high capital cost may limit the economic benefits of such a system. An abbreviated economic analysis was performed for several common residential applications in the U.S. (Table 12). While the data presented are only estimates and subject to considerable variability due to site specific factors, only the holding tank application offered potentially significant savings in water supply and sewage disposal costs. Similar results have been reported in the literature (Table 1). Additional reuse for lawn watering could render a greywater reuse system more economically attractive. The previously mentioned problems with lawn watering reuse would have to be considered, however. Multi-dwelling use of a recycle system may also make them more cost effective.

In summary, household greywater is a wastewater containing sufficient quantities of organic materials, suspended solids and fecal bacteria to warrant careful treatment prior to reuse. While the onsite recycling of greywaters has been demonstrated as an effective, user acceptable water reuse strategy, the technology has only limited application at this time. While simple homeowner-built and commercially manufactured systems can produce an effluent suitable for toilet flushing, effluent suitability for regular lawn watering is marginal. Further, demands for lawn irrigation water are limited in many parts of the United States. Yet, if only reuse for toilet flushing is proposed, simpler, more cost-effective water conservation fixtures are available that provide similar flow reductions [18]. Finally, potential problems exist with installation of the typical systems and routine homeowner maintenance is required for their proper functioning.

ACKNOWLEDGMENTS

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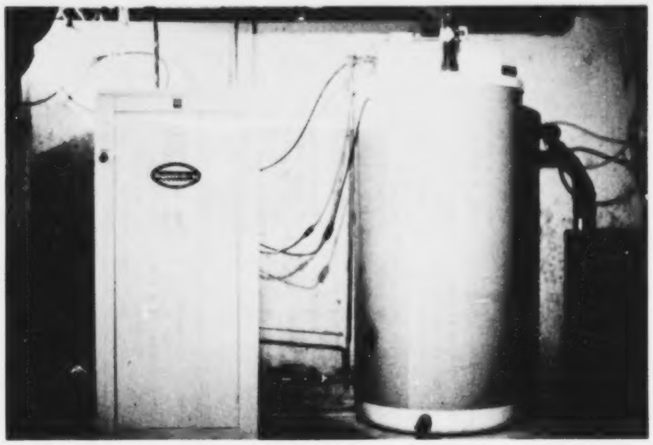

FIGURE 1. AQUASAVER GREYWATER RECYCLE SYSTEM

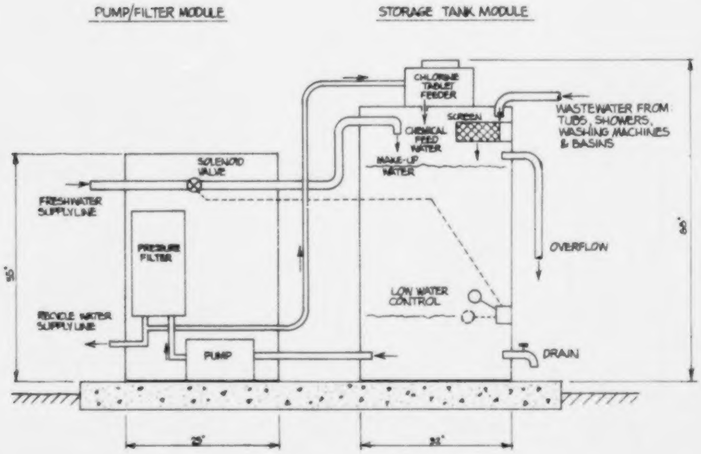
PUMP/FILTER MODULE
STORAGE TANK MODULE
CHLORINE TABLET FEEDER
SCREEN
WASTEWATER FROM: TUBS, SHOWERS, WASHING MACHINES & BASINS
CHEMICAL FEED WATER
MAKE-UP WATER
SOLENOID VALVE
FRESHWATER SUPPLYLINE
PRESSURE FILTER
OVERFLOW
LOW WATER CONTROL
RECYCLE WATER SUPPLYLINE
PUMP
DRAIN
50"
60"
25"
32"

FIGURE 2. AQUASAVER SYSTEM SCHEMATIC

TABLE 1. SUMMARY OF PREVIOUS DEMONSTRATION PROJECTS - HOUSEHOLD WATER REUSE

STUDY	TYPE OF STUDY	REUSE SCHEME	UNIT PROCESSES	FLOW REDUCTION	COST EFFECTIVE	COMMENTS
o McLaughlin, (1975)	o Demonstration of one pilot system in actual residence	o Reuse of bathing and laundry wastewaters for toilet flushing	o Sedimentation o Diatomite filtration	o 22.6 percent reduction in total water use	o Cost effective only in areas where water was very limited or waste disposal systems were severely overloaded	o Need for filter was questionable o Disinfection process was recommended o Minimal O & M but maintenance was req'd approx. every 6 months
o Cohen & Wallman, (1974)	o Demonstration of three prototype systems in actual residences	o Reuse of bathing and laundry wastewaters for toilet flushing & lawn watering	o Sedimentation o Chlorine disinf. o Diatomite & cartridge filt.	o 29% average flow reduction for toilet flush and lawn watering o 25% average flow reduction for toilet flushing only	o Economically attractive only in areas where septic systems with poor soils or other inadequacies were encountered	o Regular Maintenance req'd at approx. 3 mo. intervals o Homeowner acceptance was fairly positive o Improved septic system was noted
o Hypes & Collins (1974)	o Laboratory simulation of household use	o Reuse of bathing and laundry wastewaters for toilet flushing	o Sedimentation o Diatomite filt. o Chlorine disinf.	o 77% reduction in freshwater requirements for flushing when compared to a standard toilet	o Not assessed	o Unprocessed bath and laundry waters cannot be reused without treatment due to odors & particulate matter o Disinfection process recommended
o Bennett & Linstedt (1975)	o Laboratory evaluation of unit processes to treat wastewater for reuse	o Reuse of bathing, laundry and dishwasher wastewaters for toilet flushing and lawn watering	o Aerobic biotreatment o Sedimentation o Dual media filtration o Carbon adsorp.	o None reported	o Economical only under extreme water cost and wastewater disposal conditions	o Dual media filtration relatively ineffective o Disinfection process recommended
o Putnam (1977)	o Laboratory evaluation & assessment of washwater reclamation technology at NASA	o Treatment of laundry, shower, sink, dishwater and experiment wastewaters for removal of suspended, dissolved & microbiological materials	o Filtration o Ultrafiltration o Carbon adsorp. o Ion exchange o Chem, pre-treatment o Reverse osmosis o Hyperfiltration	None reported	o Not assessed	o Cartridge filtration, carbon adsorption, ion exchange & Pasteurization chosen in final assessment on the basis of simplicity, weight, oper. pressure & reliability

TABLE 2. CHARACTERISTICS OF HOME WASHWATER RECYCLE SYSTEMS*

UNIT	AQUASAVER	WATER WAY	ETOMS
Processing scheme	Coarse straining, Chlorination, Sedimentation/holding Pressure filtration	Sedimentation Pressure filtrations (sand, limestone, charcoal), Chlorination, Pressure tank	Fiberglass filter Sedimentation/holding Sand filtration, Iodination, Pressure tank
Resource Requirements:			
Water	Maybe	Maybe	Maybe
Power	Yes	Yes	Yes
Fuel	-	-	-
Other	Chemicals	Chemicals	Chemicals
Application Considerations:	o Separate toilet supply and drain lines o Vent lines for system o Space for unit	o Separate toilet supply and drain lines o Vent lines for system o Space for unit	o Separate toilet supply and drain lines o Vent lines for system o Space for unit
Additional Maintenance	Quarterly: Replenish chemicals, clean filter cartridge, clean storage tank, clean influent screen.	Semi-annually: Reactivate carbon. Other?	Replenish disinfectant chemicals once a year, change fiberglass filter every 2-3 months. Other?
Development Stage	Fully developed	Final development	Significant development remaining
Manufacturer/ approximate cost	Aquasaver, Inc., Baltimore, Md. $2850	Owl Corp., Verona, WI $3500	Water-Cyk Corp., Vienna, WA -----

*Based upon manufacturers' literature and communication with manufacturer by project staff.

TABLE 3. WATER USE AND WASTE FLOW CHARACTERISTICS[a]

Usage	Statistic	Unit	Residence	
			NE	VAR
Interior Water Use	Mean	Lpcd	126.7	78.0
	S.D.	Lpcd	58.1	68.1
	95% CI	Lpcd	112.7-140.6	58.8-97.2
	Range	Lpcd	47.3-364.3	15.1-280.1
	Max	Lpch	113.6	68.1
Toilet Water Use[b]	Mean	Lpcd	33.1	24.7
	S.D.	Lpcd	18.2	10.7
	Range	Lpcd	9.4-106.2	7.3-49.8
	Max	Lpch	22.0	22.3
Non-Toilet Water Use	Mean	Lpcd	126.7	75.7
	S.D.	Lpcd	58.1	67.6
	Range	Lpcd	47.3-364.3	14.2-274.2
	Max	Lpch	113.6	68.1
Toilet Fixture Use	Mean	Lpcd	2.65	2.00
	Volume	L	12.5	12.3
System Overflow	Mean	Lpcd	32.7	17.2
	S.D.	Lpcd	30.8	34.1
	Range	Lpcd	0-137.1	0-160.6
Freshwater Makeup	Mean	Lpcd	0	0.33
	S.D.	Lpcd	-	1.5
	Range	Lpcd	-	0-9.7
Data Points	Total	Days	69	51
Usage Period	Total	Days	329	318
Residents[c]	= —	—	4(17,19)	5(4,6,14)

[a] Results of individual hourly and daily measurements collected during usage period.

[b] Toilet water use is recycled greywater, not freshwater.

[c] Total residents with childrens' ages (yrs.) in parentheses.

TABLE 4. REDUCTIONS IN DAILY INTERIOR FRESHWATER USE AND WASTEWATER FLOW[a]

Comparison	Statistic	Home NE		Home VAR	
		Lpcd	%	Lpcd	%
Existing Toilet vs Recycle System[b]	Mean	32.9	20.6	22.3	22.3
	UL 95% CI	34.4	19.7	23.7	19.6
	Maximum	20.8	5.4	23.7	7.8
13.2 L Toilet vs Recycle System[b]	Mean	34.8	21.6	24.2	23.7
	UL 95% CI	36.3	20.6	25.7	20.9
	Maximum	26.9	6.9	25.7	8.4
18.9 L Toilet vs Recycle System[b]	Mean	50.0	28.3	35.6	31.3
	UL 95% CI	52.6	27.2	37.8	28.0
	Maximum	70.8	16.3	39.4	12.3

[a] Based upon analysis of individual daily measurements from the data period with the recycle system by utilizing the measured fixture usage data and the stated toilet flush volumes. Assume no freshwater is needed to meet flushwater demands.

[b] Recycle system used to produce flushwater for stated toilet unit.

TABLE 5. PHYSICAL-CHEMICAL WATER QUALITY, RESIDENCE [NE]

PARAMETER	UNITS	STATISTIC	RAW WASHWATER	STORAGE EFFLUENT	RECYCLE WATER
BOD_5	mg/L	Mean (n)	125 (7)	100 (6)	74 (10)
		S.D.	52	28	25
		Range	33-193	52-130	34-110
COD	mg/L	Mean (n)	242 (5)	204 (6)	216 (7)
		S.D.	73	46	28
		Range	169-355	123-259	171-256
TS	mg/L	Mean (n)	794 (6)	950 (7)	1040 (9)
		S.D.	168	114	172
		Range	626-1076	770-958	860-1400
TVS	mg/L	Mean (n)	128 (6)	166 (7)	172 (8)
		S.D.	48	59	69
		Range	62-180	126-262	124-324
TSS	mg/L	Mean (n)	36 (4)	18 (4)	12 (5)
		S.D.	14	7	3
		Range	21-55	13-28	8-15
TVSS	mg/L	Mean (n)	33 (4)	15 (4)	10 (5)
		S.D.	11	5	3
		Range	20-47	11-22	6-15
TKN	mg/L	Mean (n)	5.8 (6)	4.8 (7)	5.2 (10)
		S.D.	2.7	2.8	3.8
		Range	2.0-10.1	1.5-9.2	0.3-10.8
NH_4-N	mg/L	Mean (n)	0.6 (4)	0.5 (4)	0.2 (6)
		S.D.	0.6	0.8	0.3
		Range	0.35-1.4	0.1-1.6	0-0.7
NO_2-NO_3-N	mg/L	Mean (n)	0.5 (4)	0.5 (3)	0.4 (5)
		S.D.	0.5	0.2	0.4
		Range	0.3-1.23	0.35-0.67	0-0.9
Total P	mg/L	Mean (n)	1.0 (6)	2.8 (7)	1.0 (11)
		S.D.	0.5	3.6	0.6
		Range	0.08-1.7	0.18-10.5	0.2-2.1
TURB	NTU	Mean (n)	42 (5)	42 (6)	36 (9)
		S.D.	13	6	6
		Range	26-55	30-47	27-41
pH	-	(n)	-		13
		Range	-		7.0-7.8
Total Avail. Cl_2	mg/L	Mean(n)	-		4.2 (15)
		S.D.	-		6.1
		Range	-		0-19
Fecal Coli	Log no./ 100/mL	Mean (n)	- (5)	-	-(8)
		Range	1.90-7.34	-	0-<2.7

TABLE 6. PHYSICAL-CHEMICAL WATER QUALITY, RESIDENCE [VAR]

PARAMETER	UNITS	STATISTIC	RAW WASHWATER	STORAGE EFFLUENT	RECYCLE WATER
BOD_5	mg/L	Mean (n)	147 (6)	200 (6)	185 (8)
		S.D.	45	89	80
		Range	80-215	60-319	58-317
COD	mg/L	Mean (n)	276 (5)	389 (6)	383 (8)
		S.D.	56	134	133
		Range	230-359	136-511	201-577
TS	mg/L	Mean (n)	810 (6)	1143 (7)	1108 (9)
		S.D.	215	248	298
		Range	623-1086	834-1503	536-1496
TVS	mg/	Mean (n)	179 (6)	282 (7)	259 (9)
		S.D.	56	93	91
		Range	117-259	142-394	92-369
TSS	mg/L	Mean (n)	92 (6)	71 (7)	66 (9)
		S.D.	64	24	31
		Range	39-211	40-100	27-124
TVSS	mg/L	Mean (n)	38 (6)	38 (7)	36 (9)
		S.D.	19	24	15
		Range	16-68	12-86	17-56
TKN	mg/L	Mean (n)	5.7 (5)	9.8 (3)	9.1 (5)
		S.D.	2.4	6.3	4.8
		Range	2-8	5.4-17.0	4.0-16.0
NH_4-N	mg/L	Mean (n)	1.2 (4)	1.8 (2)	1.6 (3)
		S.D.	1.1		1.7
		Range	0-2.6	1.4-2.2	0-2.0
NO_2-NO_3-N	mg/L	Mean (n)	0.4 (3)	1.1 (2)	1.2 (4)
		S.D.	0.2		0.8
		Range	0.2-0.6	0.2-2.0	0.2-2.0
Total P	mg/L	Mean (n)	0.3 (2)	-	-
		S.D.	-	-	-
		Range	-	-	-
TURB	NTU	Mean (n)	-	-	-
		S.D.	-	-	-
		Range	-	-	-
pH	-	(n)	-	-	6
		Range	-	-	6.8-8.2
Total Avail. Cl_2	mg/L	Mean (n)	-	-	4.7 (11)
		S.D.	-	-	7.8
		Range	-	-	0-25
Fecal Coli	Log no./ 100 ml	Mean (n)	- (5)	-	- (6)
		Range	5.04-7.78	-	2-4.78

TABLE 7. NSF RECYCLE/REUSE SYSTEM WATER QUALITY STANDARDS[a]

PARAMETER	CRITERIA C-9	STANDARD 41
Turbidity	$\leq$100 JTU	$\leq$90 JTU
Total Coliform	$\leq$1 org./100 ml.	$\leq$240 org./100 ml.
BOD_5	$\leq$influent	$\leq$45 mg/L as 7 day running ave. $\leq$30 mg/L as 30 day running ave.
TSS	$\leq$90 mg/L	$\leq$45 mg/L as 7 day running ave. $\leq$30 mg/L as 30 day running ave.
Odor	acceptable by panel	non-offensive
Total Residual Cl_2	$\geq$ 0.1 mg/L	—

[a] Adapted from NSF Standard 41 and Basic Criteria C-9.

TABLE 8. WATER QUALITY CRITERIA FOR LANDSCAPE IRRIGATION (Culp et al., 1979)

PARAMETER[a]	UNIT	CRITERIA
BOD_5	mg/L	20
Total Dissolved Solids	mg/L	1200
Total Suspended Solids	mg/L	15
Nitrogen	mg-N/L	-
Oils & Grease	mg/L	Free From
pH	-	6.0-9.0
Fecal Coliform	No./100 mL	2.2

[a] plus 21 additional elements and compounds

TABLE 9. STORAGE TANK SLUDGE CHARACTERISTICS[a]

Parameter	Home NE 1	Home NE 2	Home VAR 1	Home VAR 2
BOD_5	3500	5160	8130	-
COD	-	-	15920	-
TS	14150	14240	37200	11000
TVS	6630	7280	10430	5300
TSS	10740	13590	-	-
TVSS	5220	6680	-	-
TKN	75	423	-	-
TP	1.8	10.8	-	-

[a] Based upon analyses of grab samples taken during two different maintenance routines.

TABLE 10. ESTIMATED WASHWATER RECYCLE SYSTEM COSTS[a]

Cost Item	Conventional Toilets	Washwater Recycle System
Capital Cost	$110	$2850
Installation Cost	$ 30	$ 400
Total Installed Cost	$140	$3250
Annual Operating Cost		
Power:	0	$ 3.00/yr.
Chemicals	0	$52.00/yr.
Maintenance Costs	?	≈12 man-hours/year

[a] Based on installation of one fixture in a new dwelling.

TABLE 11. PROJECTED WATER CONSERVATION AT TYPICAL RESIDENTIAL DWELLINGS WITH WASHWATER RECYCLE SYSTEMS[a]

Characteristic	Conventional Toilet Fixtures		Washwater Recycle System
	18.9 L (5.0 gal) (A)	13.2 L (3.5 gal) (B)	
Flush Volume			0
L freshwater/use	18.9	13.2	0
% Reduction from (A)	0	30	100
% Reduction from (B)	-	0	100
Daily Water Use			
No Reduction, Lpd	756	-	-
Reduction, Lpd	0	79	265
Reduction, %	0	10.5	35
Reduced flow, gpd	756	677	491

[a] Based on a total daily flow of 756 Lpd with 265 Lpd or 35% contributed by conventional toilet usage of 3.5 uses/person. Recycling for toilet flushing only.

TABLE 12. ABBREVIATED ECONOMIC ANALYSIS OF GREYWATER RECYCLE SYSTEMS AT RESIDENTIAL DWELLINGS [a]

Application / Assumptions	Conventional 13.2 L (3.5 gal) Toilet	Greywater Recycle Systems
Base Conditions		
Installed cost	\$140	\$3250
Increased cost over conv. toilet	0	\$3110
Daily flow reduction	10.5%	35%
Yearly flow reduction	28840 L	96580 L
City Water & Sewer		
Water and sewer cost saving @ \$0.50/kiloliter	\$14.40	\$48.30
Payback period, New	0 years	-[b]
Payback period, Retrofit	9.7 years	-[b]
Rural Holding Tank		
Pumpage cost savings @ 0.5¢/Liter	\$144	\$483
Payback period, New	0 years	7.3 years[c]
Payback period, Retrofit	1.0 years	7.6 years[c]
Reduced Drainfield Sizing		
Drainfield cost savings @ \$13.50/M^2 ; 90 M^2 req'd	\$128	\$425
Net cost savings, New	\$128	-\$2685 (loss)
Remedy Overloaded Drainfield		
Drainfield cost savings @ \$16.00/M^2; 28 M^2 expansion area needed for 30% overload	-[b]	\$448
Net cost savings, retrofit	-[b]	-\$2802 (loss)

[a] Based on data shown in Tables 8 and 9 and assumptions presented in this table. No maintenance costs were included.

[b] Annual operating costs exceed water/sewer cost savings.

[c] Pumpage cost savings less annual operating costs used in calculation

[d] Does not provide 30% reduction.

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THE POTOMAC ESTUARY EXPERIMENTAL WATER TREATMENT PLANT: A CASE STUDY OF TREATING A HEAVILY POLLUTED SOURCE

Michael C. Kavanaugh, William P. Ball, Karen B. Carter,
Alan F. Cassel, Harold T. Glaser, Carol R. James,
Thomas E. Sadick, Richard S. Holmgren, Jr.,
William R. Hancuff, Jr., John DeBoice,
Larry Tubbs, and R. Rhodes Trussell

James M. Montgomery, Consulting Engineers, Inc.
Washington, D.C., Walnut Creek, and Pasadena, California

INTRODUCTION

In the past two decades, the Army Corps of Engineers has conducted several studies on water supply problems in the Northeastern region of the United States. The Northeastern Water Supply Study (NEWS), completed in 1977(1) recommended numerous strategies for meeting short-term and long-term water shortages in the region. As a consequence of the preliminary recommendations of this study completed in 1973, the United States Congress passed the Water Resources Development Act, PL 93-251, a section of which directed the Army Corps of Engineers to evaluate the feasibility of using the Potomac River tidal fresh estuary as a supplemental source of water for the Washington Metropolitan Area (WMA). This feasibility study was expected to include the design, construction, and evaluation of the performance of a 1 mgd demonstration water treatment plant.

The specific objectives of this project were: (1) to determine the treatment efficiency of the demonstration plant with respect to a broad range of water quality parameters, (2) to estimate the process and mechanical reliability of a full-scale treatment plant, (3) to estimate water treatment costs for a full-scale plant of 100 to 200 mgd capacity, and (4) to determine if the water produced by the demonstration plant was of potable quality.

The overall project, initiated in 1975, is being funded by the Army Corps of Engineers, and is under the administrative and technical direction of the Washington Aqueduct Division, of the U.S. Army Engineer District Baltimore. The design of the demonstration plant was completed by Malcolm Pirnie in 1976 and construction was completed in mid-1980. James M. Montgomery, Consulting Engineers, Inc. of Washington, D.C. and Pasadena, California was contracted in 1980 to operate, maintain and evaluate the performance of the Estuary Experimental Water Treatment Plant (EEWTP), over a three-year project period.

The EEWTP is situated on the grounds of the Blue Plains Wastewater Treatment Plant in Southwest Washington D.C., a site selected to permit use of two influent source waters, nitrified effluent from the Blue Plains Treatment Plant and water from the Potomac River estuary. The plant is located approximately 28 kilometers from Little Falls which is the beginning of the tidal fresh estuary, and 166 kilometers upstream from the Chesapeake Bay. The plant intake extracts water from the portion of the estuary known as a tidal fresh salinity zone defined to contain less than 5,000 mg/L total dissolved solids (TDS). Approximately 30 kilometers below the intake to the plant, TDS have reached levels as high as 5,000 mg/L in the month of January of a normal hydrologic year. Thus, the high salinity zone remains far below the intake for the EEWTP, under normal conditions.

WATER SUPPLY OVERVIEW IN THE WASHINGTON METROPOLITAN AREA

The WMA is characterized by an abundant rainfall which normally provides adequate supplies for the 3.6 million inhabitants. A recent water supply study conducted by the Army Corps of Engineers suggests, however, that potential water shortages may occur in the WMA under severe drought conditions within this century.(2)

The three main alternatives for meeting the projected water deficits which may occur in the Washington Metropolitan Area are: (1) demand reduction, by means of conservation and various regulatory changes, such as new plumbing codes; (2) increasing the efficient use of existing supplies by reregulation between existing water entities or through finished water interconnections; (3) augmenting or increasing existing supplies through local storage, upstream storage, raw water interconnections, exploitation of groundwater supplies or by using the Potomac River estuary as a supplemental source. Evaluation of this latter alternative is the primary focus of this project.

This paper presents an overview of the first few months of operation of the EEWTP, including brief descriptions of project procedures and results of plant monitoring programs.

PROJECT SCOPE

The Congress has specified a project duration of three years, including six months of plant start-up, two years of plant operations and six months for plant deactivation and preparation of the final report. Beneficial occupancy of the EEWTP was carried out by JMM on 18 August 1980, and plant operation began on 16 March 1981, less than four weeks after the target start-date.

During the first year of the scheduled two years of plant operations, the project scope includes (1) performance evaluation of a standard process combination similar to local water treatment plant practices, (2) comparison of the finished water produced by the EEWTP with finished waters from three local water treatments plants in the WMA, (3) evaluation of individual process performance, (4) optimization studies to determine an improved process sequence for the second year of operation and to optimize the design criteria for the first year process combinations, and (5) preparation of preliminary cost estimates for the 100-200 mgd (4.4-8.8 m^3/s) future water treatment plant.

During a second year of operations, additional studies will include (1) the evaluation of alternative treatment combinations as selected based on the results of the first year of the project, (2) evaluation of lime and alum coagulant recovery, and (3) evaluation of demineralization processes. The final report will be submitted to Congress as part of the Washington Metropolitan Area Water Supply Study. The report will also be evaluated by a committee of the National Academy of Sciences-National Academy of Engineering for the scientific validity of the results, with review comments submitted to Congress one year following project completion.

SELECTION OF INFLUENT MIX

The EEWTP has the flexibility of using either Blue Plains nitrified, unchlorinated effluent or Potomac River Estuary water. During normal hydrologic years, the water quality in the River will differ from that expected under severe drought conditions. Thus, simulation of the expected influent water quality which might be treated by a prototype plant during drought conditions, required selection of an appropriate mix of the two influents.

To simulate the expected water quality in the river under 1930 drought hydrologic conditions, the Dynamic Estuary Management (DEM) Model was employed. This model can predict the levels of conservative constituents in the estuary under various hydrologic boundary conditions. Figure 1 illustrates the results of a simulation of TDS levels in the Potomac River estuary at Chain Bridge, near the head of the estuary, and at Potomac Park located 14 km below Chain Bridge, approxiamtely midway between the head of the estuary and the present site of the EEWTP. The hydrologic boundary conditions include 1930 drought flows, 2020 demands, a 400 mg/L TDS use increment, and a drought duration of 90 days.

Under these conditions, the maximum TDS level at Chain Bridge is expected to be approximately 450 mg/L. If this were the location of the future water treatment plant, the maximum TDS level would not exceed the secondary drinking water standard of 500 mg/L; however, if the future treatment plant were located further downstream at Potomac Park, TDS levels would be expected to exceed 600 mg/L.

Based on the results of the TDS simulation, estimates can be made of maximum levels of conservative constituents expected in the estuary under drought conditions. This provides a quantitative basis for selecting the appropriate mix of the two influent streams using existing monitoring data to characterize the estuary and Blue Plains nitrified effluent. It was found, however, that no specific mix would provide an exact match between projected and expected water quality levels.

In addition, several parameters of potential health significance cannot be modeled accurately by the DEM model. After consideration of these constraints on a quantitative selection of the influent mix an equal mix ratio was selected. Table 1 contains a comparison of projected water quality for selected parameters at Potomac Park with the expected influent water quality assuming an equal mix. The projected maximum values are based on the TDS simulation results of the DEM model. The estimated values using an equal mix are based on available monitoring data from Blue Plains, and the estuary. Projected values are compared with selected water quality goals, which are discussed in a subsequent section.

As can be seen, an equal mix ratio provides influent water quality parameters that are generally lower than projected maximum values at Potomac Park, suggesting that spiking studies should be conducted to evaluate plant performance under maximum stress conditions. Ammonia levels, however, are expected to exceed projected values.

As can be seen, the 50/50 mix is not expected to provide an influent water quality that provides an exact match of the modeled water quality parameters. The proposed mix represents a compromise between projected levels of parameters of marginal health significance, principally inorganics and unspecified levels for parameters of known or probable health significance including trace metals, trace organics, TOX and asbestos fibers.

WATER QUALITY GOALS

In order to specify guidelines for selection of treatment process combinations and operating conditions, water quality goals have been selected for physical, microbiological and chemical contaminants expected or known to be present in the influent mix. These are summarized in Table 2. As noted, the bases for setting these goals are (1) known to be achievable by existing water treatment practices, and (2) a goal of lower health risks in the finished water.

For the physical and microbiological contaminants the selected goals are generally lower than the maximum contaminant levels (MCLs) specified by EPA. The total coliform goal is 0.1/100 ml. Given an influent total coliform count of approximately 10^5/100 ml, the demonstration plant must achieve a six-log coliform reduction. Turbidity levels in the estuary have exceeded 200 turbidity units. Adequate particulate removal will be necessary to meet the goal of 0.2 TU. The water quality goals for the four heavy metals shown in Table 2 are generally lower than the MCLs, based on the judgement that the present MCL may be too high. The goal for asbestos fibers has been set at 100,000 fibers/L corresponding to the minimum detection limit for this particulate contaminant.

The water quality goal for total organic carbon (TOC) is 3 mg/L, based on maintaining low trihalomethane and total organic halogen levels in the finished water, with chlorine used as the primary disinfectant. The goal for total trihalomethanes has been set at 50 ug/L in order to minimize health risks from exposure to these compounds.

PLANT DESCRIPTION

The demonstration plant was designed to include standard water treatment processes with several additional process options including predisinfection with either ozone or chlorine, capabilities for sludge recycle to the rapid mix tank, upflow and downflow carbon columns and final disinfection with either ozone, chlorine or ultraviolet radiation. The plant also contains facilities for demineralization using ion exchange, electrodialysis or reverse osmosis. The hydraulic capacity of the main plant is 1 mgd (43.8 L/s). The demineralization processes have a hydraulic capacity of approximately 10,000 gpd. The selected process sequence and operating conditions for the first year of operation are summarized in Table 3.

MONITORING PROGRAM

In order to determine the success of the EEWTP in meeting the selected water quality goals and to evaluate the performance of individual processes, an intensive sampling program was developed by the Army Corps of Engineers. A summary of the sampling sites and frequency for a number of key parameters is summarized in Table 4. As shown, the finished water produced by the EEWTP will be compared with the water quality of the finished water from three water treatment plants serving customers in the Washington Metropolitan Area. The selection of sampling frequency was based on the statistical evaluation of expected influent variability, and on cost constraints.

SAMPLE HANDLING

Samples are collected either manually or by automatic composite samplers located at the plants site or at the off-site local water treatment plants. Standard preservative procedures are followed. For the organics analyses, a special no-head space, automatic composite sampler, developed by EPA is used. Samples are collected each morning, distributed into appropriate containers, and either analyzed in the on-site laboratory or shipped to the JMM Pasadena Environmental Research Laboratory. Generally, two to three shipments are transported per week. Sample loss to date has been minimal.

ANALYTICAL METHODS

A brief summary of all analytical methods utilized by the on-site lab and the JMM ERL is shown in Table 5. References for each methods are as noted.

DATA MANAGEMENT

The magnitude of the analytical and testing programs planned for this project demand that most data be computerized. System design features include the need to store and provide access to over a million data records during the course of the project. Data management requirements include producing reports for laboratory quality control and reports for performance evaluation of the EEWTP. The core of the computer system is a VAX 11/780 computer located in the Pasadena office of JMM. This system is an interactive computer with approximately two megabytes of core storage and a practically unlimited amount of virtual storage. It is very flexible, allows a number of simultaneous users, and contains a special software package ideally suited for management of large quantities of data.

Analytical results produced in the Pasadena ERL laboratory are processed through a HP lab computer system which provide laboratory reports and sample inventory control. Some analytical data is transmitted directly from laboratory instruments to the computers; other data must be manually stored. This data is then transfered from the laboratory computer to our central storage location on the VAX 11/780.

Analytical and plant operations data generated on-site are initially input manually to a MINC 11-03 computer and transfered periodically via a leased telephone line to the VAX 11/780. On-site computer terminals permit ready access to the data base for evaluation of individual processes and overall plant performance.

PRELIMINARY RESULTS - COMPARISON OF EFFLUENTS

Full-scale operation of the EEWTP commenced in mid-March 1981. A key project objective is the comparison of the finished water produced by the EEWTP with the quality of finished waters produced by the local water treatment plants in the WMA. Subsequent discussions summarize these data based on one to three months of available analytical data for selected water quality parameters.

Microbiological Parameters

Shown in Table 6 are results for total coliform and viruses, the minimum quantification limit for each paraemter, and two statistical parameters, the median value and the 90 percentile value. Based on approximately one month of data, the median coliform level in the EEWTP effluent in lower than the MCL of 1 coliform/100 ml, although positive coliform results have been observed. In contrast, the median level for one local water treatment plant is none detected. Thus, the microbiological quality of the EEWTP effluent for total coliform is inferior to the local water plant, but it still meets drinking water standards.

At the present time only eight virus samples have been analyzed. Presently, no viruses have been detected in any of the four finished waters.

Metals

The water quality of the four finished water with respect to four important heavy metals included in the primary drinking water standards is summarized in Table 7. Shown is the minimum quantification level for each metal, the number of analyses, and the median and the 90% percentile statistics. For all metals shown, with the exception of arsenic, the median values are not detected based on approximately one month of data. The levels of arsenic in the local water treatment plants are higher than that observed in the EEWTP finished water; however, they are far below the maximum contaminant level of 50 ug/L and far less than the MCL of 50 ug/L or the water quality goal of 10 ug/L. Based on these data, the quality of the EEWTP is meeting all the water quality goals for metals.

Additional Inorganic Parameters

Table 8 summarizes the water quality of the four effluents with respect to a number of additional inorganic parameters, including total dissolved solids (TDS), nitrate, sodium, manganese, and asbestos fibers. For these parameters, with the exception of asbestos fibers, the quality of the EEWTP effluent is inferior to the local finished water. TDS median levels are approximately 100 mg/L higher reflecting the presence of treated wastewater in the influent. Nitrate levels are also considerably higher; however, the 90 percentile level is below the nitrate MCL. The sodium levels are also exceeded in the local supplies, again reflecting the use of the influent 50/50 mix. THe median level exceeds the suggested sodium MCL of 20 mg/L, but the health significant of this sodium level is uncertain. At the present time, the manganese levels in the EEWTP effluent exceed the secondary standard of 0.05 mg/L, and 90 percent of the time exceed 0.17 mg/L. This indicates a potential aesthetic problem with the finished water; however, applications of potassium permanganate since June have reduced manganese levels below the secondary standard. Finally, the median value for asbestos fibers found in the effluent is below detection limits (0.1 million fibers per liter). Approximately 10 percent of the time asbestos fibers greater than the minimum quantification limit have been found in the three local water treatment plants. Again, the health significance of ingesting asbestos fibers is uncertain, and no standards for asbestos have yet been proposed by EPA.

Organic Parameters

Table 9 lists the quality of the four effluents with respect to two collective organic parameters, TOC and TOX and one group of specific organic compounds, the total trihalomethanes. For these parameters the quality of the EEWTP effluent is superior to that shown in the finished waters of the three local water treatment plants. For TOC, the lower levels achieved in the EEWTP results from the use of granular activated carbon. As a consequence of the lower TOC value in the finished water of the EEWTP, and the use of a lower free chlorine residual than used by the local water treatment plants, the total trihalomethane and total organic halogen levels at the EEWTP are below those observed for the local plants. The median TTHM level for the EEWTP is 11 ug/L based on 24 samples or approximately 10 weeks of data. Median values for TOX are approximately half those observed in off-site plants. The health significance of these differences is not presently known, however.

All of the four finished waters are being monitored for a large number of synthetic organic chemicals (SOCs) including those in the EPA priority pollutant list. Three separate organic fractions are being analyzed, the purgeable volatile organics, the base neutral acid (BNA) organic extracts and the pesticide/herbicide/PCB fraction. As summarized in Table 10, a total of 136 compounds can be identified in these three fractions. Presently, based on only eight samples, approximately 44 volatile organics have been found at levels exceeding the minimum detection limit (0.1 ug/L), while seven compounds have been found in BNA fraction. In contrast, however, only nine purgeable volatile organics and three BNA compounds have been found at levels exceeding the minimum quantification level.

Table 11 summarizes the results for three specific SOC's found in the effluents, carbon tetrachloride, perchloroethylene and dibutyl phthalate. The concentration of these compounds found in the EEWTP influent range from 1 to 10 ug/L for PCE, 1 to 3 ug/L for carbon tetrachloride and approximately 1 ug/L for dibutyephthalate. The median level based on eight samples is below detection limits for all three of these compounds. Ten percent of the time, however, levels on the order of 0.1 ug/L have been observed in the EEWTP effluent and at off-site locations. Preliminary results would indicate that for the synthetic organic chemicals included in the EPA's priority pollutants, the quality of the effluent from the EEWTP is comparable to that supplied by the local water treatment plants. The health significance of these results are, however, uncertain.

SUMMARY

The tidal fresh estuary zone of the Potomac River near Washington, D.C. has never been used as a water supply source by local water utilities. One of the alternatives for meeting possible future water supply shortages in the Washington Metropolitan Area is the use of this untapped resource. In 1974, Congress directed the Army Corps of Engineers to investigate the technical and economic feasibility of this alternative by constructing and operating a 1 mgd demonstration water treatment plant.

Operation and monitoring of the demonstration plant, known as the Experimental Estuary Water Treatment Plant (EEWTP) commenced in March of 1981. This paper has presented an interim progress report on the first few months of effluent monitoring data. The water quality of the finished water from the EEWTP has been compared to the finished water produced by three local water treatment plants using conventional water treatment technology with no additional treatment such as air-stripping or granular activated carbon for organics control.

Based on preliminary results, the finished water from the EEWTP is meeting all EPA primary and secondary drinking water standards.

For those parameters not regulated by EPA, the EEWTP finished water quality is comparable to the quality of the local finished waters. For some organic compounds, including the collective organic parameters TOC and TOX and the total trihalomethanes, the quality is superior. These data are preliminary, however, and detailed statistical comparisons will be made when more data become available.

A more fundamental problem, however, is determining if the water produced from a simulated polluted source, in this case an equal mix of estuary water and nitrified activated sludge effluent, can be defined as "potable". Currently, there are no objective standards which answer this question when unprotected polluted surface sources, or treated waste waters are used as drinking water sources. Limited toxicological tests on all four finished waters are now in progress, including the Ames mutagency assay and the mammalian cell transformation test. The results of these in vitro tests may provide some basis for determining the relative risks associated with ingestion of the finished water from the EEWTP. Additional toxicological tests would be highly desireable; however, limitations on available funds appear to limit the extent of these tests, particularly in vivo measurements.

Future reports will provide a more detailed summary of plant monitoring data, statistical evalaution of the comparison of different effluents, and detailed cost estimates of the water treatment alternatives.

ACKNOWLEDGEMENT

This project is funded by the Army Corps of Engineers (ACE). We wish to thank the Army Corps and the Washington Aqueduct Division (WAD) for permission to publish this information.

The technical support provided by the staff of the Washington Aqueduct Division was essential for the successful start-up of plant operations. In particular, we wish to thank Lieutenant Colonel James Dunmyer, of the Army Corps of Engineers, and Mr. Harry Ways, Mr. Perry Costas, Mr. Doug Pickering, Mr. Leonard Ignatowski, and Mr. Ira Thompson, all of the WAD.

REFERENCES

1. "Northeastern United States Water Supply Study, Summary Report," U.S. Army Corps of Engineers, North Atlantic Division, July 1977.

2. "Metropolitan Washington Area Water Supply Study for the Potomac River Users, Progress Report," Army Corps of Engineers, Baltimore District, August 1979.

TABLE 1

COMPARISON OF PROJECTED WATER QUALITY AT POTOMAC PARK WITH ESTIMATED PLANT INFLUENT WATER QUALITY USING EQUAL MIX RATIO

Parameter (2)	JMM Projected Maximum Value at Potomac Park Intake	Estimated Value Equal Blend Ratio	Water Quality Goal	Removal Efficiency Required to Meet WQ Goal (5)
Total Coliform (MPN/100 mL)	NM(1)	$2x10^5$	0.1	99.99995
TDS	542	366	500	
Cl	106	69	—	
Total-P	0.4	0.6	—	
NH_3-N	1.8	4.2	—	
NO_3-N	7.3	6.4	5.0	22
Cd	0.09	0.008	0.01	
Cr (total)	0.17	0.004	0.05	
Ni	0.06	0.005	—	
Pb	0.09	0.003	0.025	
Zn	0.06	0.04	—	
TOC	NM	8.5	3	65
TOX (ug Cl/L)	NM	200	150	(5)
Purgeable Organics (ug/L)	NM	12-20	5	60-75
Turbidity (NTU)	NM	15	0.2	98.67
Asbestos (M fibers/L)	NM	22	0.1	99.55
Algae (no./ml)	NM	750	—	

1) NM = not modeled.
2) Units in mg/L except as noted.

TABLE 2

POTOMAC PROJECT WATER QUALITY GOALS

PARAMETER	UNITS	EPA MCL	GOAL	BASIS
PHYSICAL AND MICRO-BIOLOGICAL				
TOTAL COLIFORM	No/100 mL	1	0.1	Achievable
STANDARD PLATE COUNT	No/mL	—	5-	Achievable
ENTERIC VIRUSES	PFU/L	—	0.01	Achievable
TURBIDITY	TU	1	0.2	Achievable
COLOR	ACU	15	3	Achievable
INORGANIC				
ARSENIC	mg/L	0.05	0.01	MCL may be high
CADMIUM	mg/L	0.01	0.01	MCL
CHROMIUM (T)	mg/L	0.05	0.05 (VI)	Cr (VI) only issue
LEAD	mg/L	0.05	0.025	MCL may be high
NITRATE-N	mg-N/L	10.0	5.0	MCL may be high
ASBESTOS FIBERS	Mf/L	—	0.1	Min. Detection Limit
ORGANIC				
TOC	mg-C/L	—	3.0	THM Control
TOX	mg-Cl/L	—	0.150	Achievable
TTHM	mg/L	0.1	0.05	Lower Health Risk
PCE	ug/L	—	4	10^{-6} Risk Levels
TCE	ug/L	—	4.5	

TABLE 3

PROCESS SEQUENCE AND PROPOSED OPERATING CONDITIONS FIRST YEAR PLANT OPERATIONS - EEWTP

Unit/Process	Operating Conditions
1. Influent mix-estuary /nitrified effluent	Equal mix Q = 0.5 mgd (350 gpm)
2. Microscreens	35 um polyester fiber screen Combined flow through one unit 7.3 gpm/ft^2
3. Aeration	Surface aerator 2 hp/1000 ft^3 Detention time (D.T.) = 20 mins.
4. Rapid mix	2 tanks in series D.T. = 1 min/tank G = 400 sec^{-1}
5. Coagulants	Primary: alum Dose = 40-70 mg/L as alum Coagulant aid: anionic polymer (Hercofloc 1018) Dose = 0.1 - 0.5 mg/L as required
6. Flocculation	Two tanks in series D.T. = 20 min/tank Vertical turbine G (tank 1) = 80-100 sec^{-1} (50-60 rpm) G (tank 2) = 40-60 sec^{-1} (35-45 rpm)
7. Sedimentation Basin	Horizontal: submerged weirs Detention Time = 4.5 hours Q/A = 470 gpd/ft^2 (0.84 m/h)
8. Intermediate Disinfection	Disinfectant: Cl_2 Target Residual: 1 mg/L, total Cl_2 Dose = 2-10 mg/L Contact time = 10 sec ahead of filter

TABLE 3

PROCESS SEQUENCE AND PROPOSED OPERATING CONDITIONS
FIRST YEAR PLANT OPERATIONS - EEWTP
(Continued)

Unit/Process	Operating Conditions
9. Filters	Dual Media: 20" anthracite/10" sand Flow rate = 2.9 gpm/ft^2 (7.3 m/h) with two filters in operation Rate control: rate of flow control, effluent control valve Filter aid - none at present Backwash: surface wash, backwash at maximum flow of 16 gpm/ft^2 (40 m/h)
10. GAC Columns	Carbon: ICI 816 Hydrodarco (lignite based carbon) Empty Bed Contact Time (EBCT)/Column = 7.5 min (Total EBCT = 15 min) Bed Depth = 9 ft (2.74 m) Q/A = 9 gpm/ft^2 (22.5 m/h) Operation: 2 downflow pressure columns in series Proposed regeneration criteria: a) TOC removal 50% or b) TOX 100 ug/L Method of regeneration: Off-site by ICI
11. Post Disinfection	Disinfectant: Cl_2 Dose: 2-6 mg/L Contact Time: 60 min Chlorine residual target: between 1 and 2 mg/L free Cl_2

TABLE 4

POTOMAC PROJECT
ROUTINE WATER QUALITY TESTING PROGRAM

	SITES						
	Blue Plains	Estuary	Blend	Filter Effluent	GAC Effluent	Finished Water	Local WTPs (3)
Parameter	1	2	3	6	13	16	
Total/Fecal Coliform	DG	DG	—	—	DG	DG	
Viruses/ Parasites	MG	MG	—	MG	MG	MG	MG
Ames	—	—	—	—	—	WG	WG
Mammalian	—	—	—	—	—	MG	MG
TOC	DC		DC	C	C	DC	DC
TOX	DC		DC		DC	DC	DC
TTHMs			S		S	S	S
SOCs			T		T	T	T
Metals (29)			DC	DC		DC	DC
Minerals	DC	DC	DC		DC	DC	DC
Asbestos	WC	WC	WC	WC		WC	WC

S = DC Twice/week
T = 3 day composite/3 weeks
DC = Daily composite
DG = Daily grab
MG = Monthly grab
WG = Weekly grab
C = Continuous

TABLE 5

POTOMAC PROJECT
ANALYTICAL METHODS
JMM ENVIRONMENTAL RESEARCH LABORATORY

Parameter	Method	Reference
Alkalinity	automated methyl orange	EPA 310.2
Ames test	elute from resin, bacterial bioassy	Mutation Research 31:347-364 (1975)
Ammonia	automated phenate	EPA 350.1
Asbestos	electron microscope	EPA interim
Bromide	ion chromatography	Dionex Manual
Chloride	automated Hg $(SCN)_2$	EPA 325.2
Cyanide	automated colorimetric	EPA 335.2
Endotoxin	limulus assay	Difco
Fluoride	automated complexone	EPA 390.3
Hardness	ICP for Ca and Mg	Fed Register 12/79
Mammalian Cell Transformation	elute from resin, transformation assay	Cancer Research 33:3234-3249 (1974)
Metals	ICP	Fed Register 12/79
MBAS	Colorimetric	EPA 425.1
NO_3+NO_2	automated Cd reduction	EPA 353.2
Odor	threshold/characterization	EPA 140.1
Orthophosphate	automated ascorbic acid	EPA 365.1
Parasites	filter, count	EPA-600/9-79-001
Radiological	proportional counter	SM 703
Salmonella	membrane	SM 912C
Silica	ICP	ASTM pg. 13
Sulfate	automated chloranilate	EPA 375.1
SOC (priority pollutants)	GC/GC-MS	Fed Register 12/79
Taste	Comparison	SM 211 A
THM	GC/ECD	EPA 501.2
TOC	chemical-UV oxidation	EPA 415.1
TOX	oxidation/microcoulometric detection	TOX Joint Task Group Report
TON	automated phenate	EPA 351.2
Viruses	concentrate, MPN	APHA 913 (modified)

EEWTP JMM LABORATORY

Chlorine demand	titration	ASTM 1237
Chlorine residual	amperometric	SM 409 C
Color	chloroplatinate	EPA 110.2

TABLE 5

POTOMAC PROJECT
ANALYTICAL METHODS

EEWTP JMM LABORATORY
(Continued)

Parameter	Method	Reference
Electrical conductivity	conductivity bridge	EPA 120.1
Oxygen, dissolved	membrane electrode	EPA 360.1
Ozone	iodometric	SM 423 A
pH	electrometric	EPA 150.1
Solids, total dissolved	evaporation	EPA 160.1
Solids, total suspended	filtration	EPA 160.2
Temperature	thermometric	EPA 170.1
Turbidity	nephelometry	EPA 180.1
Total coliform	MPN	SM 908 A
Fecal coliform	MPN	SM 908 C
Standard plate count	pour plate	SM 907

TABLE 6

POTOMAC PROJECT
COMPARISON OF EFFLUENTS
MICROBIOLOGICAL CONTAMINANTS

Parameter (MQL)		EEWTP	WTP 1	WTP 2	WTP 3
Total Coliform	N	43	36	---	---
(0.02/100 ml)	Median	0.08	ND		
	90%	0.23	ND		
Viruses	N	8	8	8	8
(1 IFU/1250 L)	Median	ND	ND	ND	ND

TABLE 7

POTOMAC PROJECT
COMPARISON OF EFFLUENTS METALS

Parameter (MQL)		EEWTP	WTP 1	WTP 2	WTP 3
Arsenic (.0002)	N	42	21	36	32
	Median	ND	.0003	.0002	.0002
	90%	0.005	.0006	.0005	.0004
Cadmium (.0008)	N	42	21	36	32
	Median	ND	ND	ND	ND
	90%	.001	.008	.0012	ND
Chromium (T) (0.003)	N	42	21	36	32
	Median	ND	ND	ND	ND
	90%	ND	ND	ND	ND
Lead (.0003)	N	42	21	36	32
	Median	ND	ND	ND	ND
	90%	.001	.001	.002	.001

TABLE 8

POTOMAC PROJECT
COMPARISON OF EFFLUENT INORGANIC PARAMETERS

Parameter (Units)		EEWTP	WTP 1	WTP 2	WTP 3
TDS (mg/L)	N	69	70		
	Median	239	142	—	—
	90%	300	171		
Nitrate + Nitrite (mg-N/L)	N	41	19		
	Median	8.3	1.5	—	—
	90%	9.8	2.2		
Sodium (mg/L)	N	42	21	36	32
	Median	25.5	7.3	11.9	7.6
	90%	28.8	10.2	12.6	10.1
Manganese (mg/L)	N	42	21	36	32
	Median	.06	.003	.004	.003
	90%	0.17	.006	.009	.008
Asbestos (Mf/L)	N	10	10	11	10
	Median	ND	ND	ND	ND
	90%	ND	0.13	0.13	0.26

TABLE 9

POTOMAC PROJECT
COMPARISON OF EFFLUENT ORGANIC PARAMETERS

Parameter (Units)		EEWTP	WTP 1	WTP 2	WTP 3
TOC (mg/L)	N	61	38	53	45
	Median	1.2	1.8	3.6	2.0
	90%	1.9	2.4	5.0	3.3
TOX (ug/L)	N	59	38	53	45
	Median	145	280	310	350
	90%	230	415	355	460
TTHM (ug/L)	N	24	24	21	20
	Median	11	60	46	52
	90%	30	88	56	76

TABLE 10

POTOMAC PROJECT
SUMMARY - FINISHED WATER QUALITY ANALYSES FOR SYNTHETIC ORGANIC CHEMICALS

Fraction (MQL, ug/L)	Compounds Searched	Compounds Found (greater than MDL)	Compounds Quantified
Purgeable Volatile Organics (0.1)	53	44	9
BNAs (0.1-10)	56	7	3
Pest/Herb/PCB (0.1-1.0)	27	0	0

TABLE 11

POTOMAC PROJECT
COMPARISON OF EFFLUENT SYNTHETIC CHEMICALS

Compound (MQL ug/L)		EEWTP	WTP 1	WTP 2	WTP 3
CCl_4 (0.1)	Median(1)	NQ	NQ	NQ	NQ
	90%	0.1	NQ	0.1	NQ
PCE (0.1)	Median	NQ	NQ	NQ	NQ
	90%	0.1	NQ	NQ	NQ
Dibutyl	Median	ND	ND	ND	ND
Phthalate (0.5)	90%	ND	ND	ND	ND

(1) Based on eight samples, 3-day composites

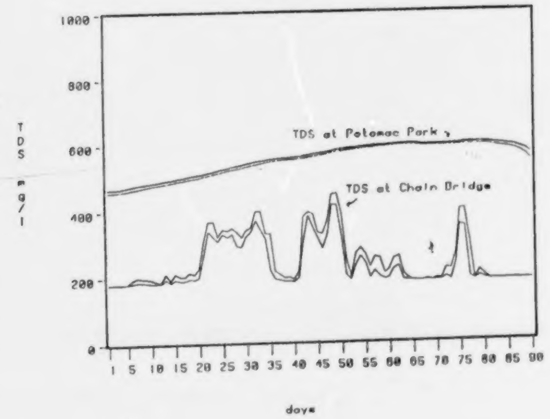
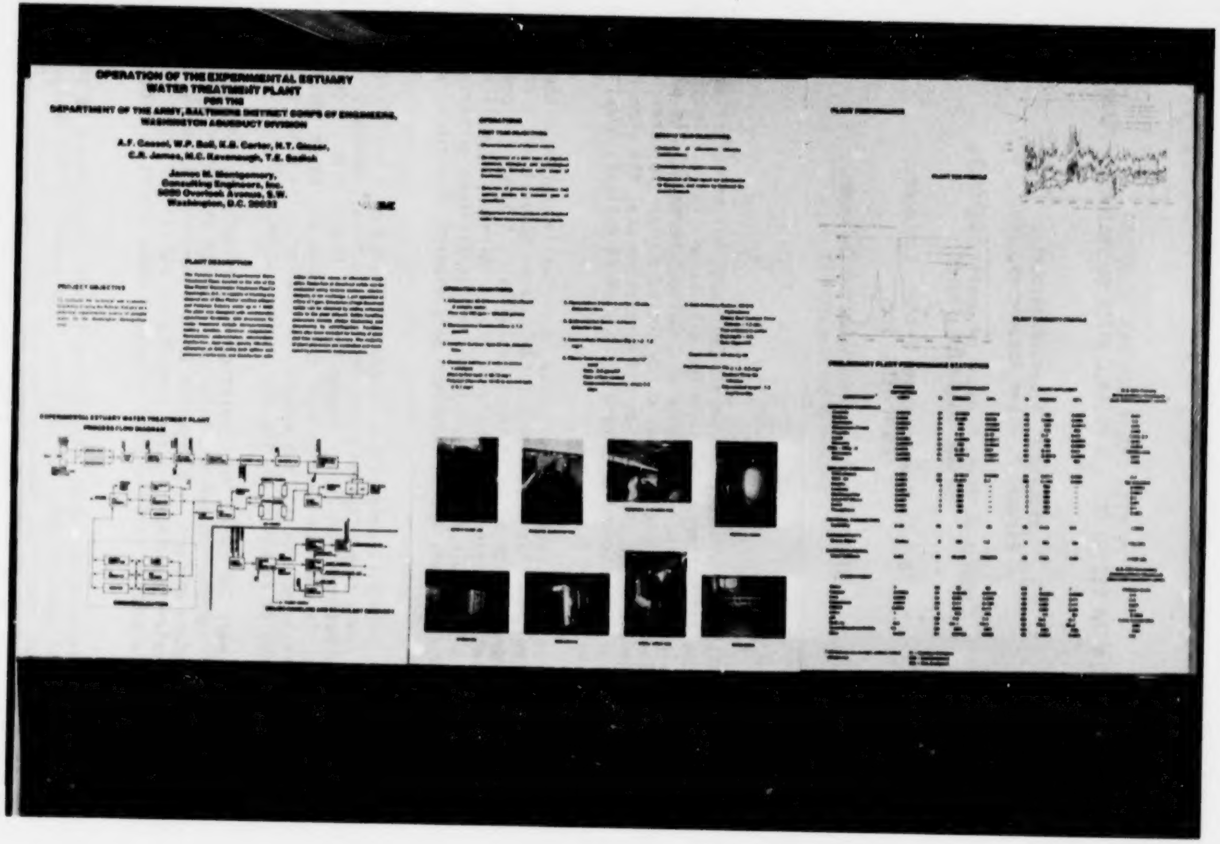


FIGURE 1

Results of DEM Model Simulation.

Daily Average and Maximum TDS, 1930 Flowby, Chain Bridge Intake Last 90 Days of Simulated Drought Period. Demands Based on Army Corps of Engineers Projections, 2020.



OPERATION OF THE EXPERIMENTAL ESTUARY WATER TREATMENT PLANT
FOR THE
DEPARTMENT OF THE ARMY, BALTIMORE DISTRICT CORPS OF ENGINEERS,
WASHINGTON AQUEDUCT DIVISION

A.F. Cassel, W.P. Ball, K.B. Carter, H.T. Glaser,
C.R. James, M.C. Kavanaugh, T.E. Sedlak

James M. Montgomery,
Consulting Engineers, Inc.
5000 Overlook Avenue, S.W.
Washington, D.C. 20032

PROJECT OBJECTIVE

PLANT DESCRIPTION

EXPERIMENTAL ESTUARY WATER TREATMENT PLANT
PROCESS FLOW DIAGRAM

PLANT PERFORMANCE

PRELIMINARY PLANT PERFORMANCE STATISTICS

PB82-223207

PROCESS EVALUATION AND SELECTION IN THE DESIGN OF A POTABLE WATER DEMONSTRATION PLANT

Richard P. Arber, President,
Richard P. Arber Associates, Inc.

Stephen W. Work, Manager of Quality Control,
Denver Water Department

Carl L. Hamann, Chief Process Engineer,
CH2M Hill, Inc.

William C. Lauer, Reclamation Engineer,
Denver Water Department

INTRODUCTION

The availability of water to Denver, Colorado, has been critical throughout its history. This problem will become increasingly acute as the population of the front range of Colorado increases. As part of its effort to address this problem, which includes plans for conventional supply development, conservation and successive use, the Denver Water Department has embarked on a long-range plan to evaluate and implement potable water reuse.

Recognizing that potable water reuse is virtually unproven, the Denver Water Department has initiated a potable reuse demonstration program. This program, which began in the late 1960's is intended to demonstrate the technical feasibility of potable reuse. Already accomplished are several pilot scale research projects, public attitude surveys, alternative reuse studies, and has involved many experts in advanced waste treatment (AWT).

In 1975, CH2M Hill completed a Conceptual Design of a one million gallon per day reuse demonstration plant intended to treat secondary effluent from the Metropolitan Denver Sewage Disposal District No. 1 to potable quality. This design incorporated the thoughts and experiences of many water treatment experts from around the country. The basic process configuration selection during the study is shown on Figure 1.

In the years following the completion of the Conceptual Design, additional information and knowledge of treatment processes resulted in some process changes. In December 1978, a meeting held among the Denver Water Department, their consultants and the EPA which finalized the basic process configuration. Figure 2 shows the final process flow design.

The entire program, which is expected to take eight years to complete, will cost approximately $29 million. This amount is for design, construction, operation, health effect and analytical studies. The EPA is participating by means of a cooperative agreement in which they will contribute $7 million.

DEMONSTRATION PROJECT GOALS

The goals[1] for the demonstration program include 1) demonstrating reliability 2) proving product water safety 3) generation of public acceptance 4) generating regulatory agency acceptance 5) providing data for large scale (up to 100MGD) implementation.

These goals were paramount while evaluating and selecting unit processes and incorporating them into a final design.

FLOW RATE

The flow rate for the Denver Water Department Water Reuse Demonstration Plant was selected to be 1 million gallons per day.[2] Although this sizing is somewhat arbitrary, it permitted realization of many of the goals and criteria set for the project. It will allow a simulation of full-scale plant operation. In addition, if the plant was sized at a lesser flow rate, difficulty would be encountered in finding available equipment. By making the plant 1MGD, the need for custom-made equipment could be avoided.

For economic reasons, the processes downstream of first stage activated carbon are sized at 0.1MGD. The original concept placed this flow split after the final granular activated carbon treatment. This change occurred with the design approximately 10% complete in an effort to reduce the costs of the ozonation and second stage activited carbon processes. It was felt that both of these processes sized at 0.1MGD would still provide acceptable treatment performance data while realizing a significant cost reduction.

RELIABILITY

One of the primary goals of the Denver project is to demonstrate that drinking water can safely and reliably be produced from secondary sewage treatment plant effluent.[3] To this end, the operating philosophy of plant requires full flow (1MGD) capability in all but unusual circumstances. In the event that full flow cannot be realized, the plant can be operated at 1/2 flow, (0.5MGD) rather than discontinuing operation completely. Provisions for operating at 0.5MGD have been incorporated into each unit process. Only the most unusual circumstances would dictate cessation of operation. However, it should be noted that no provisions have been made to alter operation of the secondary treatment process at the Metro Denver Plant. The availability of the raw water source is therefore standard for the industry.

Electrical power outages periodically occur in the vicinity of the demonstration plant. In the event of a power outage, the reuse plant will shut down with critical valves failing closed to ensure the integrity of the product water. In addition, limited standby power generation capabilities have been provided to avoid damage to certain unit processes and provide power to the control system and emergency lighting.

Since the major goal relative to reliability is to maintain maximum flow through the plant while producing safe water, each unit process makes use of multicontactors or reaction vessels to provide the necessary redundancy. In some cases, 100% reliability is provided (such as the lime system) and in other cases, two contactors, each with half flow capacity, are provided. For example, the filtration system has three filters, each with a nominal capacity of 0.5MGD. Normally two filters will be in service with the third being in standby for use during backwashing. However, if one filter is inoperable, the filtration system can still be operated at 1MGD, except for the short periods during backwashing where the flow would have to be reduced to 0.5MGD.

It should be also noted that each process has the capability of being bypassed or having the process sequence rearranged. While this capability will not be used to mitigate process failure, in the unlikely occurance of total process failure, it does provide the flexibility to test various process configurations, i.e., elimination of individual unit processes in the treatment train.

INFLUENT SOURCE

The source of water for the reuse demonstration plant will be unchlorinated secondary effluent from the Metropolitan Denver Sewage Disposal District No. 1 Plant (Metro). The Metro plant is a high-purity oxygen activated sludge plant, located approximately 1/2 mile from the Denver Water Department Reuse Demonstration Plant site. The water is pumped from the secondary clarifier effluent through to the head of the reuse plant.

As noted earlier, there is a possibility that the Metro Plant could have an extended outage of their process at the pure oxygen plant. In this event, temporary piping from Metro's conventional activated sludge plant adjacent to the oxygen plant could be installed to provide raw water for the reuse project.

CHEMICAL SYSTEM

The plant contains provisions for receiving, storing and feeding a number of process chemicals. Nine such chemical systems are included, which will handle deliveries of bulk quantities. The criteria for selecting the size of the storage system was based primarily on delivery volumes.

Each of the bulk chemical storage systems consists of totally enclosed containment basins and redundant feed systems. Figure 3 shows the chemicals incorporated into the plant and number of pumps and feed systems.[3]

LIME TREATMENT/RECARBONATION

The lime clarification system for the reuse plant is a high-dose (400 milligrams per liter) process with the flexibility to operate with either single or two stage recarbonation. Several plants around the country have experienced good results with single stage recarbonation.[5] However, in Denver's case, there is a concern about the potential impact on downstream process of higher suspended solids and calcium concentrations which may be experienced with the single stage mode. This concern is due primarily to the fact that clinoptilolite selective ion exchange for ammonia removal is downstream of the lime process. This natural zeolite is also selective for calcium. There is concern that high calcium concentrations in the influent to the clino system may tend to "blind" the ion exchange sites, thus reducing the capacity of the clino system.

In order to avoid this potential problem, yet still examine the benefits of single stage recarbonation, flexibility for operating in a two-stage recarbonation mode has been incorporated into the design. Both of these modes - single and two stage - will be compared during the initial operational period of the plant. Recarbonation of the lime clarified effluent will be accomplished using liquid carbon dioxide. Due to the low gas flowrates, adequate mixing could not be achieved with gas alone. Therefore, the contact basins include turbine mixers to promote the reaction. Sulfuric acid will serve a backup to the carbon dioxide for pH control.

SOLIDS HANDLING

The 1975 Conceptual Design recommended inclusion of lime recalcination to recover and reuse the lime. However, during a subsequent evaluation of this process, it was concluded that significant cost savings could be realized by elimination of this capability without materially reducing the results of the demonstration project. This conclusion was reached largely due to the fact that recalcination is practiced in many locations now and that information could be gained from those operations. Also, it appears that lime recalcination is becoming less and less economical at lower flow rates. The break-even point for recovery of lime now appears to be between 50 and 100MGD in plant capacity. The final design eliminated recalcination and included provisions for pumping all of the waste solids back to the Metro Denver plant for disposal.

BALLAST PONDS

Flow equalization prior to filtration will be provided by two ballast ponds with a capacity of approximately 200,000 gallons each. They will each provide approximately 4.8 hours detention time at full flow. These ballast ponds are necessary to provide a "wide spot in the line" to receive recycle flows such as backwash water, etc. In addition, these ponds will serve as wet wells for pumps to the downstream pressure vessels. Another advantage of having these ballast ponds is that they provide for some flexibility in the upstream processes, i.e., if the latter are inoperable for a period of time, the ballast ponds can provide water for the downstream processes.

FILTRATION

As mentioned earlier, three 0.5MGD pressure filters will be provided. The primary evaluation in this process was that of selection of media. Pilot studies performed by the Denver Water Department[6] evaluated rapid sand, dual and mixed media. The conclusion of that study indicated that dual media should be incorporated into the design of the demonstration plant.

SELECTIVE ION EXCHANGE

The primary method of removing ammonia from the water will be selective ion exchange using the natural zeolite clinoptilolite. The zeolite will be contained in pressure vessels mounted vertically. The configuration of these vessels changed somewhat from the Conceptual Design in that originally they were to be mounted horizontally. Results from operating installations indicated that regeneration of the zeolite in the "crescent" at the sides of the circular tank was ineffective. It appears that this is due primarily to the wall effects resulting from the curvature of the tank. Therefore it was concluded that this problem may be avoided by placing the tanks vertically.

The bed volume throughput criteria for the ion exchange system was designed more conservatively than would be indicated by results of the Denver Water Department's pilot studies.[7] This conservatism was due to the fact that full-scale operating installations have experienced less volume throughput per ton than the pilot studies. In addition, the concern of calcium fouling indicated above also entered into the decision to provide more conservatism.

SELECTIVE ION EXCHANGE REGENERATION AND RECOVERY SYSTEM

The ammonia removal and recovery process (ARRP) is similar to those operating at the Occoquan, Virginia and Tahoe-Truckee, California treatment plants. This process involves a closed system stripper-absorber concept. Figure 4 is a conceptual sketch of that process.

The concept of recovering the regenerante solution for the clinoptilolite involves regenerating the zeolite with first a "dirty" regenerante solution and then subsequently "cleaner" solutions containing less ammonia until the zeolite is fully regenerated.

The ARRP system recovers the regenerante solution with the greatest ammonia concentration by processing it through the stripper-absorber system. The process includes an ammonia stripping unit and an ammonia adsorption unit. Both of these units are essentially sealed from the outside air, but are connected by appropriate ducting. The stripping gas, which initially is air, is maintained in a closed cycle. The stripping unit operates essentially in the same manner as is now done in a number of systems with the exception that the gas stream is recycled rather than outside air being used in a single pass manner.

Most of the ammonia discharged to the gas stream from the stripping unit is removed in the absorption unit. The absorbing liquid is maintained at a low pH (generally below pH 4) to convert absorbed and dissolved ammonia gas to ammonium ions. This effectively traps the ammonia and also has the effect of maintaining the full driving force for absorbing the ammonia since dissolved ammonia gas does not build up in the absorbent liquid. The absorption unit is a packed tower, with sprays similar to the stripping unit.

The absorbent liquid initially is water with acid added to obtain the low pH. If sulfuric acid is added, an ammonium sulfate salt solution is formed. This salt solution continues to build up in concentration and the ammonia is finally discharged from the absorption device as a liquid or solid (precipitate) blowdown of the abosrbent. Makeup water and acid are added as necessary. The by-product is a solution of ammonium sulfate which has value as a fertilizer.

As mentioned earlier, this process is in place at both Tahoe-Truckee and Occoquan plants and has been designed similarly. The only significant difference is that the stripper towers and absorber towers are identically designed to permit their operation to be interchanged. The primary purpose for this approach is to help avoid the problem of scale accumulation in the stripper tower. That is, as scale begins to accumulate in the stripper tower, the towers will be reversed. The tower formerly used as the stripper will become the absorber, and the sulfuric acid mist will tend to dissolve the scale.

ACTIVATED CARBON

The configuration of the graular activated carbon (GAC) process has experienced major changes since the completion of the Conceptual Design. These changes in criteria and concept have occurred as a result of operating experiences at other facilities. As originally envisioned in the Conceptual Design, the GAC columns were to be single-stage countercurrent upflow units. Redundancy was to be provided by standby columns. However, due to concern about carbon fines fouling the downstream reverse osmosis process, it was determined that the GAC columns should be operated downflow, even though flexibility for other modes of operation will be provided.

The major impact resulting from this change in concept is economics. First of all, downflow carbon contactors must be approximately 50% taller than upflow contactors to provide for bed expansion during backwash. Secondly, the carbon inventory required for downflow contactors is considerably greater than that for upflow contactors. This difference in inventory requirements is due to the fact that upflow counter current contactors "continuously" withdraw spent carbon in small increments (usually 10%) and then regenerate it. However, with downflow activated carbon, once the carbon is spent, the entire column must come off line to be regenerated and a "fresh" regenerated column brought on line.

Furthermore, with the downflow mode, the breakthrough "wavefront" moves through the column, thus requiring the contactor to be taken off line for regeneration before complete breakthrough. With countercurrent operation the isotherm or "wavefront" is maintained in a relatively static position in the column. Regenerated carbon is introduced at the top of the contactor to replace the carbon removed from the bottom.

The design at the Denver Reuse Demonstration Plant will incorporate the flexibility of operating in either upflow or downflow mode. This way, the effects of carbon fines on the downstream processes can be evaluated in light of apparent economic disadvantages of the downflow mode.

OZONATION

Breakpoint chlorination had been included in the Conceptual Design both for its disinfection potential and also to remove the residual ammonia remaining after ion exchange. Results from the Department's pilot studies have indicated that proper selection of reverse osmosis membranes will accomplish the ammonia polishing that was to be done by breakpoint chlorination. In addition, EPA indicated in discussions prior to the grant award, that they strongly opposed the use of free chlorine anywhere in the process upstream of complete organic removal. Their reasoning was based upon concern over formation of total trihalomethanes and other chlorinated organic compounds. At the same time the Department felt very strongly that a second redundant disinfection step was a necessary part of the treatment train. Therefore, the ozonation process originally placed downstream of activated carbon was moved upstream, resulting in carbon-ozone-carbon configuration. This configuration will be extensively evaluated during the operation of the facility. The merits of this configuration include the capability of operating as BAC (Biological Activated Carbon) and having an opportunity for residual organics to be absorbed after ozonation. However, the pilot studies by the Department have shown this configuration may not be especially beneficial. Furthermore, some pilot studies have shown carbon attrition in the contactor following ozonation.

CARBON REGENERATION

The original Conceptual Design envisioned a multiple hearth furnace as the method for granular activated carbon regeneration. At the time of that study, multiple hearth furnaces were the only conventionally used method of regernation. However, since that time, infrared tunnel furnaces and fluidized bed furnaces have been developed for carbon regeneration.

An evaluation done during the design based on the economics of the various furnances available, concluded that the fluidized bed furnance should be incorporated into the project. The criteria used for this evaluation was the cost for regenerating carbon from the ultimate 100MGD plant. Operation and maintenance costs and capital costs were obtained from various manufacturers for this evaluation. Other significant factors in the evaluation were carbon loss and energy requirements. The fluidized bed furnance appears to have an advantage over the other types of furnaces, especially at the larger capacity.

REVERSE OSMOSIS

As mentioned eariler, pilot studies conducted by the Denver Water Department determined that spiral wound polyamide membrane reserve osmosis units are capable of removing more than 90% of the ammonia present in the feed water. The one drawback of this type of membrane is that it is particularly susceptable to damage from upstream oxidants. However, since no chlorination will be used upstream of the reverse osmosis unit, the polyamide membrane becomes more suitable for this particular application.

As designed, the plant will consist of three parallel reverse osmosis systems, capable of treating a total of 0.1MGD. Controls, cartridge filters, chemical addition and cleaning systems are included in the packaged reverse osmosis system. The four inch diameter polyamid membranes will be configured in 4-2-1 array. Final product water recovery is specified to be approximately 90 percent.

AIR STRIPPING

Results of organic studies at Water Factory 21 at Orange County, California have indicated that air stripping for decarbonation of the water also removes a large amount of the volitile organic chemicals remaining in gaseous solution after both carbon absorbtion and reverse osmosis. Placing the strippers upstream of disinfection at the California facility eliminated most of the precursors for total trihalomethane formation.

Design considerations for organic removal are consistent with those for decarbonation, allowing industry design practice to be utilized for the decarbonators.

DISINFECTION

Because of EPA's desire to eliminate free chlorine from the treatment process, it was decided to utilize chlorine dioxide as the primary disinfectant. Since chlorine dioxide will be produced on-site from gaseous chlorine, the plant will actually have the capability to utilize either substance.

PLANT CONTROL AND DATA LOGGING

A computer system consisting of a PDP-11 Series mainframe and disk and magnetic tape storage capability will be provided in the plant. The system will receive sensor input from approximately 200 locations and manual inputs from six CRT's located in the control room, plant laboratory and the Department's Quality Control Lab at Marston. It will perform alarm and reporting functions in considerable detail in addition to storing and manipulating operating and laboratory data.

The computer system will also provide a portion of the public relations displays capability, allowing limited "hands on" manipulation by visitors.

All process equipment and valves will be remotely operable and the majority will also be operable from the control room. In this latter area, the computer will provide detailed plant status and operating information to assist the operators in decision making. No close loop computer will be provided.

SUMMARY

Design has been completed on the Denver Water Department's one million gallon per day water reuse demonstration plant. The process evaluation and selection for the plant was aimed at meeting the goals of the project: demonstrating reliability; proving product water safety; generation of public and regulatory agency acceptance; and providing data for large scale implementation.

The construction of the $16.2 million plant will be complete in the spring of 1983. Following construction, operation and subsequent product water testing will evaluate the effectiveness of the treatment process. Upon completion of the entire eight year program, Denver will be in a position to begin plans for implementation of a full-scale, 100MGD reuse program that will provide approximately 15 percent of their water by the turn of the century.

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8) "Advanced Treatment For Wastewater Reclamation at Water Factory 21," Perry L. McCarty and David G. Argo, EPA Technical Report No. 236, January 1980.

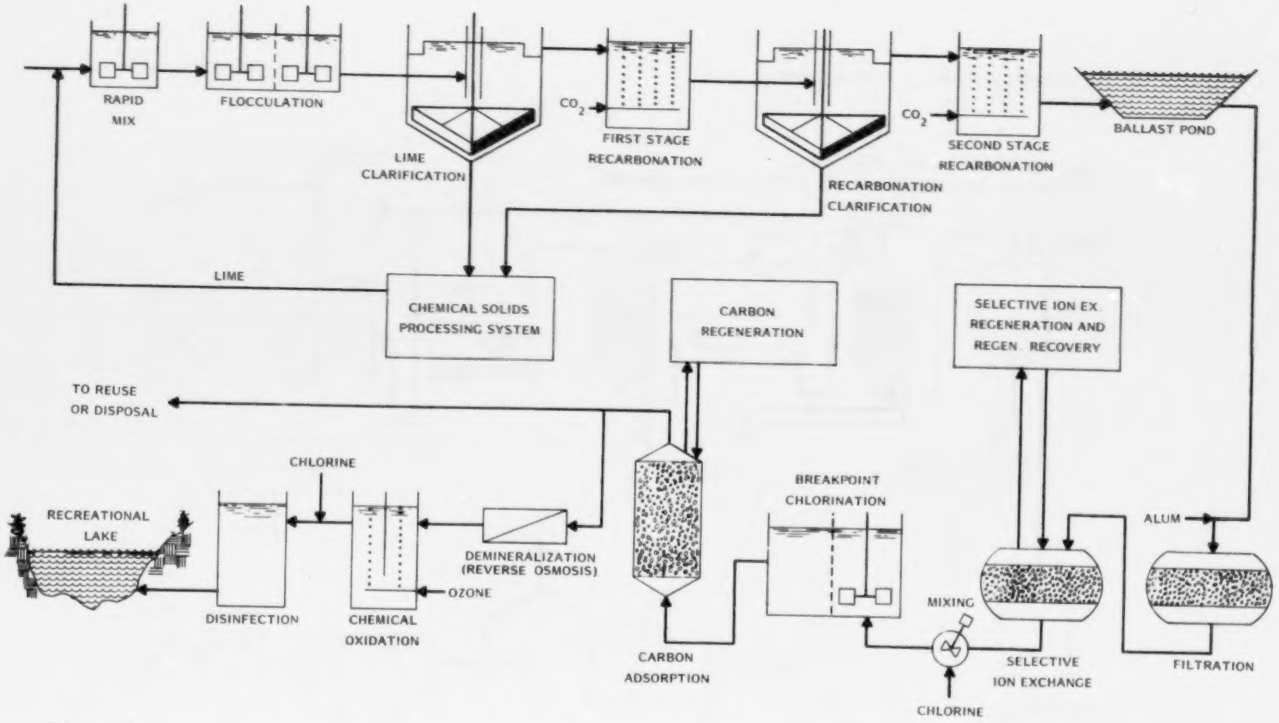
RAPID MIX
FLOCCULATION
LIME CLARIFICATION
CO_2
FIRST STAGE RECARBONATION
RECARBONATION CLARIFICATION
CO_2
SECOND STAGE RECARBONATION
BALLAST POND
LIME
CHEMICAL SOLIDS PROCESSING SYSTEM
CARBON REGENERATION
SELECTIVE ION EX. REGENERATION AND REGEN. RECOVERY
TO REUSE OR DISPOSAL
CHLORINE
RECREATIONAL LAKE
DEMINERALIZATION (REVERSE OSMOSIS)
OZONE
DISINFECTION
CHEMICAL OXIDATION
CARBON ADSORPTION
BREAKPOINT CHLORINATION
MIXING
CHLORINE
SELECTIVE ION EXCHANGE
ALUM
FILTRATION

Figure 1

Original Process Flow Configuration

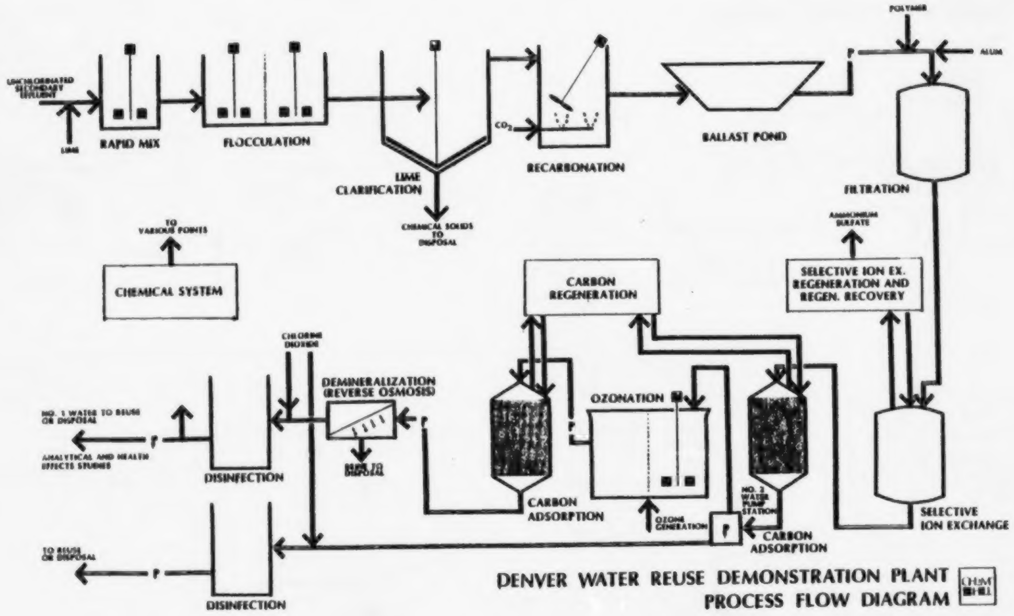
UNCHLORINATED SECONDARY EFFLUENT
LIME
RAPID MIX
FLOCCULATION
LIME CLARIFICATION
CHEMICAL SOLIDS TO DISPOSAL
CO_2
RECARBONATION
BALLAST POND
POLYMER
ALUM
FILTRATION
AMMONIUM SULFATE
SELECTIVE ION EX. REGENERATION AND REGEN. RECOVERY
SELECTIVE ION EXCHANGE
TO VARIOUS POINTS
CHEMICAL SYSTEM
CARBON REGENERATION
CHLORINE DIOXIDE
DEMINERALIZATION (REVERSE OSMOSIS)
BRINE TO DISPOSAL
OZONATION
OZONE GENERATION
CARBON ADSORPTION
NO. 2 WATER PUMP STATION
CARBON ADSORPTION
NO. 1 WATER TO REUSE OR DISPOSAL
ANALYTICAL AND HEALTH EFFECTS STUDIES
DISINFECTION
TO REUSE OR DISPOSAL
DISINFECTION
DENVER WATER REUSE DEMONSTRATION PLANT
PROCESS FLOW DIAGRAM
CH2M HILL

Figure 2

Final Process Flow Configuration

Chemical Feed Systems

Chemical	# of Pumps and Feed Systems
Polymer (2 types)	6
Sodium hydroxide	3
Aluminum sulfate	5
Generic coagulant	3
Sulfuric acid	5
Hydrochloric acid	2
Sodium chloride	1
Chlorine (& $C1O_2$)	2
Lime	2
Soda ash	4
Carbon dioxide	1
Ozone	2

Figure 3

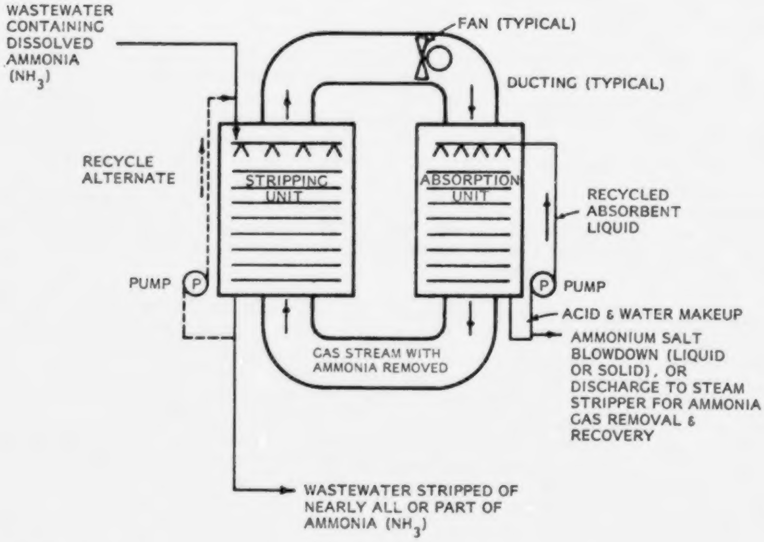
WASTEWATER CONTAINING DISSOLVED AMMONIA (NH_3)
FAN (TYPICAL)
DUCTING (TYPICAL)
RECYCLE ALTERNATE
STRIPPING UNIT
ABSORPTION UNIT
RECYCLED ABSORBENT LIQUID
PUMP
P
PUMP
P
ACID & WATER MAKEUP
AMMONIUM SALT BLOWDOWN (LIQUID OR SOLID), OR DISCHARGE TO STEAM STRIPPER FOR AMMONIA GAS REMOVAL & RECOVERY
GAS STREAM WITH AMMONIA REMOVED
WASTEWATER STRIPPED OF NEARLY ALL OR PART OF AMMONIA (NH_3)

Figure 4 Ammonia Removal & Recovery Process

PB82-223215

REDUCING THE COST OF WASTEWATER RECLAMATION

David G. Argo
Assistant Manager and Chief Engineer
Orange County Water District
Fountain Valley, California

Since the completion of Water Factory 21 (WF-21) the Orange County Water District (OCWD) has conducted an ongoing, active research program. A primary objective of this effort has been to reduce the cost of wastewater reclamation while attempting to improve the quality of the water produced. WF-21 currently reclaims up to 15 million gallons per day* of municipally treated secondary effluent. This water is injected into the groundwater basin along the Orange County coastline. The injected water provides a hydraulic barrier to prevent seawater intrusion and contributes to replenishment of the underground water supply. Successful operation over the past five years has demonstrated the feasibility and reliability of WF-21's reuse project.[1,2]

The advanced waste treatment (AWT) processes currently employed at WF-21 include lime clarification, air stripping, recarbonation, mixed media filtration, activated carbon adsorption, chlorination, and demineralization by reverse osmosis. (Figure 1 is a block flow diagram of WF-21, showing the various treatment processes schematically.) OCWD has conducted several pilot studies in an effort to develop alternative treatment trains suitable for producing water for barrier injection and other potential applications at a lower cost. The purpose of this paper is to describe the results of these research efforts.

As part of this program, OCWD has focused its attention on reducing or eliminating some of the existing processes. Earlier pilot studies[3] have explored the feasibility of the lime/RO process. It has been demonstrated that lime clarification of activated sludge effluent, followed by reverse osmosis (RO) demineralization, is capable of achieving water quality comparable to that produced by the current WF-21 treatment system. Through elimination of several treatment processes, the cost of reuse has been significantly reduced. This paper discusses the continuation of OCWD's evaluation of the lime/RO process.

A new generation of low pressure RO membranes is being developed: the thin film composite (TFC) type, primarily polyamide (PA) materials, which operate at considerably lower pressures (250 psi vs 460 psi) than the more conventional cellulosic membranes. Besides reducing pretreatment, the use of the new low pressure membranes will further reduce costs by decreasing energy requirements. This report presents data developed during the most recent operation of two low pressure TFC membranes at WF-21, using the reduced pretreatment lime/RO process.

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*See Appendix for metric equivalents.

The paper will conclude with a discussion of research efforts under way to deal with the major unsolved problem in wastewater demineralization. While the feasibility of wastewater desalting has been demonstrated, the gradual long-term fouling of the RO membrane and subsequent decline in productivity still remains to be solved. Control of membrane fouling and resultant extension of membrane life is a critical factor in controlling the cost of wastewater demineralization.

PILOT PLANT SYSTEM

OCWD constructed two identical 10,000 gallons per day (gpd) pilot RO plants for use in their research program at WF-21. The feedwater to these plants is municipal activated sludge effluent which has received lime clarification in WF-21's full scale lime clarifier. Table I summarizes the quality of the lime clarified secondary effluent. Figure 2 is a schematic of the pilot plant and pretreatment system used throughout the testing period. It is important to keep in mind while looking at the flow schematic that several processes used in pretreatment of the feedwater to the 5 mgd RO plant have been eliminated: air stripping, mixed media filtration, and activated carbon adsorption. The lime clarified secondary effluent is piped to the two 10,000 gpd pilot RO systems. Sulfuric acid is added prior to demineralization to adjust pH from 11.0 to approximately 5.5. Other treatment prior to RO includes the addition of threshold scale inhibitors (SHMP) to prevent calcium sulfate precipitation in the RO system as the water becomes increasingly concentrated during the demineralization process. Provision is also made for addition of other chemicals. Disinfection by either chlorination or sodium bisulfite can be used to retard biological growth within the RO system.

Following chemical treatment, the feedwater is filtered through a 25 micron cartridge filter for further removal of suspended solids. The feedwater pressure is then boosted to approximately 250 psig by means of a Goulds multistage centrifugal pump. The operating pressure is then adjusted by a manually operated pressure regulating valve. The pressurized feedwater is routed to a series of pressure vessels containing membrane elements. There are six individual fiberglass pressure vessels for each RO pilot system, each with an internal diameter of four inches. The first two contain four inch diameter spiral wound elements and are operated in series. The second two vessels contain a PVC pipe sleeve which reduces the internal diameter to three inches, and the elements in these are three inches in diameter. The brine flow from the second vessel becomes the feed flow to the third and fourth, which are operated in series. The last two pressure vessels are sleeved for two and one half inch diameter elements. These too are in series, and the brine flow from the fourth vessel becomes the feed for the fifth and sixth.

By reducing the diameter of the pressure vessels in series, this feed configuration allows operation of the pilot plant at high recovery rates. Thus a three array arrangement can provide recovery rates up to 87.5%. Recovery* is defined as the percent of product water to feedwater.

Each of the pilot plants was designed to provide complete indication of essential operating data. Feedwater temperature and pressure are measured. Conductivity and flow measurements are provided for the feed, product and brine, with flow totalizers for feed and product. Differential pressure is measured across the first two, four and six pressure vessels in series. This allows measurement of the pressure drop across the first, second and third arrays of the RO system.

FILMTEC PILOT STUDY

On January 29, 1981 one of the 10,000 gpd high recovery test systems was loaded with membrane manufactured by FilmTec Corporation Minnetonka, Minnesota. The membrane selected was FT-30, a TFC type membrane. The specific membrane composition is proprietary, thus currently unknown. The membrane was cast on a polyester nonwoven fabric support material. Standard components of construction were used. The brine spacers were Vexar, and the product water carrier was Dacron type cloth (tricot). Eight membrane elements were loaded into each of the pressure vessels. The eight four-inch diameter modules loaded in vessels 1 and 2 were designed with 20 ft^2 of membrane per element. The eight three-inch diameter elements loaded into vessels 3 and 4 each contained 10 ft^2 of active membrane surface area. The smaller two and one half inch diameter elements loaded into vessels 5 and 6 contained 6 ft^2 of membrane per element. When all pressure vessels were loaded with the membranes, the total system contained 576 ft^2 of active membrane surface area. FilmTec elements, 12 inches long with a 3/8 inch PVC product water tube, were constructed with a fiberglass outer shell wrap and equipped with antitelescoping devices.

Performance. Testing began on January 29, 1981, and the initial data were taken after two hours of operation. Based on these data, stoichiometric calculations were made and results are shown in Table II. As can be seen, the initial average flux** was 10.3 gal/ft^2-day, with a feed brine

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$$\text{*Recovery} = \frac{\text{product water flow}}{\text{feedwater flow}} \times 100\%$$

**Flux is the quantity of water that flows through a unit area of membrane, generally expressed in gallons per square foot of membrane surface area per day (gal/ft^2-day).

average rejection* for each pressure vessel varying from 95.7% to 97.6%. Rejection based on feed was 95.9%. The pressure drop across the six pressure vessels in series was 65 psig with a feed pressure of 200 psig.

Approximately 30 hours after initial startup, operating conditions for the FilmTec pilot plant were modified, as the manufacturer was disappointed in the flux rate achieved at startup. The FT-30 membranes were expected to provide a flux rate of almost 20 gal/ft^2-day at 200 psig, but as indicated by the data, the initial flux was only 10.3 gal/ft^2-day at 200 psig. There was also a rather rapid decline in flux during the first 30 hours. During this time, actual permeate flow decreased from 4 gpm to 3.2 gpm, or approximately 20%.

On February 8 the operating pressure was increased from 200 psi to 250 psi, causing the product flow rate to increase from 3.2 to 3.8 gpm. Since that date, the FilmTec unit has been operated at a constant pressure of 250 psig. Table III presents all the key data collected after increasing the operating pressure. The average actual flux was 9.37 gal/ft^2-day with an average rejection, based on feed, of 95.6%. Comparing the 30 hour normalized system flux** with the initial normalized flux, a 28% flux decline due to membrane compaction and fouling had occurred. Figure 3 shows the product water flow, normalized to a 77°F feedwater temperature at 250 psig operating pressure, as a function of operating time. Also shown on the same figure is product water quality. The graph indicates that following the initial flux decline that occurred in the first 50 hours of operation, the plant's performance stabilized and produced a flow that has been maintained at about 3 gpm. This corresponds to a normalized system flux of 7.5 gal/ft^2-day. This graph also indicates salt rejection has been very consistent, averaging around 97-98%. There was one brief exception, when product water quality deviated from the 40-50 μmho range which it averaged over the first 2,000 hours of operation. This occurred after 630 hours of operation and is indicated on the plot by event marker No. 4. This graph indicates a series of several noteworthy events that took

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*Rejection is the term used to describe the percentage of dissolved salts removed during desalination:

$$\text{Rejection} = \left(1 - \frac{\text{product concentration}}{\text{feedwater concentration}}\right) \times 100\%$$

**Normalized system flux is the amount of water that flows through a unit area of membrane, adjusted to standard conditions of pressure and temperature, since flux is a function of both. Throughout this report, normalized flux is adjusted to 250 psig feed pressure at 77°F.

place during the unit's operation. A summary which explains the details of each event is given in Table IV.

A review of Figure 3 and Table IV indicates that the polyamide thin film composite membrane is extremely durable. Certain key events which are listed in the table and shown on the graph require some additional explanation. The inadvertent closing of the brine valve, which occurred after 630 hours of operation, resulted in considerable scale due to precipitation of sparingly soluble salts at the membrane surface during 100% recovery operation. The fact that the system was able to partially recover by simply dissolving the scale indicates the durability of the FilmTec membrane. Removal of the scale was accomplished by repiping RO product water as the feed supply and operating the system for several days. The extremely low TDS feedwater redissolved the scale that had precipitated when the brine valve had accidentally been shut. A review of the cleanings that were performed during operation indicates that a cleaning solution consisting of 1% sodium tripolyphosphate (STP), 1% trisodium polyphosphate (TSP), and 1% ethylenediaminetetraacetic acid (EDTA) is most effective in restoring flux. (Throughout the remainder of this report, this cleaning solution will be referred to as 1-1-1). Later cleanings done under high pressure operating conditions seem to show that cleaning velocity is extremely critical in restoring system flux. It appears that the fouling layer is not as well removed without high cleaning velocities.

Some elements exposed to more than 2,000 hours of operation have subsequently been removed and cleaning tests performed on the individual elements to determine the relationship of cleaning velocity and flux restoration. Results show a pattern which suggests that the higher the velocity, the more effective the cleaning. A four inch element was removed and tested for its rejection and flow characteristics prior to cleaning. It was then cleaned at a flow rate of 5 gpm and retested for flow and rejection. The same element was then cleaned for 30 minutes at a 10 gpm cleaning rate. After testing performance conditions, the element was cleaned again at 15 gpm, tested, and recleaned at 17.5 gpm, the maximum possible cleaning velocity, due to the limitations of the cleaning pump.

The improvements in product flow from the original condition through each subsequent cleaning and the effect of salt rejection are summarized in Table V. Based on this test, the higher velocity (up to 17.5 gpm) did not adversely affect membrane salt rejection capability but did provide an increase in element output from 0.18 to 0.30 gpm. This represents an increase in flux rate of 66%. Although one third of the increase occurred after the first cleaning, each subsequent cleaning produced further improvement, indicating that the higher the cleaning velocity, the more material was stripped from the membrane element.

In an attempt to control membrane fouling and flux decline, two different chemicals were added at different points in the study to control biological fouling, which is suspected to be the principal cause of the flux decline and will be discussed in greater detail later in this report. First (Event 2), for a period of approximately 100 hours, 20 mg/l of chlorine (calcium hypochlorite) was added for two hours a day. All added chlorine was found to be combined residual chlorine, since the feedwater contained about 30 mg/l of ammonia. During this period, between 475 and 600 hours elapsed time, the membrane flux decline continued without apparent effect from the chlorine. It is significant, however, that 20 mg/l of combined chlorine residual was added to the feedwater without adversely affecting the membranes' salt rejection capability. Most TFC membranes are very sensitive to chlorine and break down very rapidly in the presence of a chlorine residual. In a later test, a single four inch element that had been in service for approximately 2,000 hours was removed from the system. This used element was then soaked for two days in a 5 mg/l free chlorine residual solution. The performance of this individual element before and after two days' exposure to 5 mg/l chlorine is summarized in Table VI.

This would suggest that simple exposure to higher concentrations of even free chlorine residual can be tolerated, at least for brief periods of time, without adversely affecting the membrane rejection performance capability. In addition, it appears that a free chlorine residual is an effective chemical for restoring flux decline. Simply soaking the membrane in 5 mg/l of chlorine resulted in almost a 30% increase in product flow rate on this particular element. This would be expected, since the primary cause of flux decline is biological growth on the membrane surface.

Besides chlorine, the addition of 1,000 mg/l of sodium bisulfite (Event 6) was started after 900 hours elapsed time. This addition has been maintained continuously since that time, and the flux decline has stabilized and product capacity has been maintained at about a 3 gpm normalized flow rate. It is hard to evaluate the effects of the sodium bisulfite on fouling. Since the flow rate has stabilized, one might conclude that the chemical addition has contributed to prevention of further flux decline. However, as a result of other work, another possible explanation has emerged. This theory indicates that once a certain fouling layer has developed, subsequent development of additional foulants reaches an equilibrium point with the velocity of flow through the system. Thus the rate of deposition of fouling material is equal to the rate of removal due to shearing of the fouling layer by velocity of the feedwater through the RO unit. OCWD plans to do further studies in an attempt to better evaluate this phenomenon. Some preliminary results of these studies will be discussed in the conclusions of this report. Since no apparent adverse effects of using sodium bisulfite have appeared, and the data indicate a possible correlation of reduced fouling with its use, the chemical has been added throughout most of the pilot study, and future experiments are planned to try to determine its role in controlling fouling.

The long-term performance of the FT-30 membrane is shown in Table VII, which gives operating data after 2,106 hours. The normalized system flux is 9.57 gal/ft^2-day, which is just slightly higher than the flux obtained after 30 hours of operation. This indicates the performance has stabilized and the system output has been maintained by cleaning. System rejection has actually improved over this period from 95.6% to 98.3%. The average removals of several key water quality constituents are listed in Table VIII. Of particular importance in reuse applications is the high removal of organics achieved. Effluent COD and TOC were reduced to below 1 mg/l with corresponding average removals of 99% and 92%, respectively.

DESALINATION PILOT STUDY

A membrane manufactured by Desalination Systems, Inc., of Escondido, California, was tested concurrently with the operation of the FilmTec low pressure RO system. The evaluation of this membrane (Desal I) began at the same time as the FilmTec study, January 29, 1981. The exact composition of this membrane's thin film barrier layer is also unknown, but it is probably similar to other TFC, PA type membranes. The porous support was cast on a polyester nonwoven fabric carrier material. Standard components were used for brine spacers, product water carrier, and adhesive. The central product water tube was manufactured from 3/8 inch PVC schedule A pipe, and all elements were 25 inches in length. Four elements were installed in both of the four inch diameter pressure vessels (Nos. 1 and 2). Each 25 inch long element contained an active membrane surface area of 60 ft, giving a total membrane surface area of 480 ft^2 in vessels 1 and 2. Four three inch diameter elements containing 30 ft^2 of membrane were loaded in vessels 3 and 4. The four 2-1/2 inch diameter pressure vessels installed in vessels 5 and 6 have 20 ft^2 of active membrane surface each, providing an additional 160 ft^2 of membrane. The total of all six vessels provides a system with an installed membrane capacity of 880 ft^2.

All of the elements were constructed with a fiberglass outer wrap and antitelescoping devices on each end. The feedwater flowed from the four inch elements to the three inch elements and then to the 2-1/2 inch elements, giving a 4,2,1 array configuration to provide for high recovery operation.

Performance. Testing began on January 29, 1981. The initial data were taken after two hours of operation and the results, based on stoichiometric calculations, are shown in Table IX. The initial system flux was 15.28 gal/ft^2-day, with a feed brine average rejection for each pressure vessel varying from 91% to 86%. Rejection based on feed was 82.5%. Pressure drop across the six pressure vessels in series was 100 psi, with a feed pressure of 200 psig. While the initial data indicated the membrane's output was excellent (normalized flux = 19.4 gal/ft^2-day), salt rejection was lower than expected. The lower salt removal, although somewhat unexpected, was not cause for dismissing this type of membrane.

In reuse applications where all the water will be demineralized, the higher salt rejections will not always be necessary or even desirable. In water reclamation, removal of constituents of potential health concern, such as organics, is more important. Table X shows the average removal of some dissolved minerals, ammonia and organics during the first 1,000 hours of operation. While some inorganics, sodium and chloride, were only reduced by 83% and 72%, removal of organics, COD and TOC remained high, with rejections of more than 90%.

Figure 4 plots the Desal I pilot plant's product water flow, normalized to a 77°F feedwater temperature at 250 psig. This figure also shows product water quality as a function of operating time and indicates key events that occurred during the pilot study. The first 300 hours of operation show a rather steep decline in product water output. During this period the normalized flow decreased from 12.3 to 6.0 gpm, a decline of 51%. Arrow No. 1 on Figure 4 marks the first attempt to clean the system. The cleaning was aborted at the request of the membrane manufacturers and all four elements from vessel 1 were removed. Analysis of the fouled elements indicated heavy biological type fouling, with a visible slime layer observed on the membrane surface. These elements were replaced and the operating pressure was increased to 250 psig. As indicated in Figure No. 4, replacement of the four membrane modules in the first pressure vessel resulted in improvement in normalized flow to approximately 8 gpm.

Shortly after plant restart at 322 hours, the addition of sodium bisulfite for two hours a day was begun (arrow No. 2). The initial dosage of 140 mg/l was later increased to 1,000 mg/l for two hours a day (arrow No. 3). Product water quality varied from 200 to 325 µmhos over the first 1,000 hours of operation. Following the rather steep initial flux decline and replacement of the membranes in the first vessel, the normalized flow stabilized at an average of about 8 gpm for the next 800 hours. This would suggest that sodium bisulfite addition helped reduce fouling. Possibly the bisulfite, which is a reducing agent, alters the micro-environment by removing oxygen sufficiently to retard biological growth. To date, no definite correlation has been established, but other studies, some of which are discussed later, are designed to provide more information on sodium bisulfite and its effect on membrane performance.

A sudden rapid increase in product water total dissolved solids (TDS) was observed shortly after 1,000 hours. At the same time, a much smaller increase in product capacity also occurred. These two phenomena indicated membrane failure. The plant was left in operation through June 3, 1981, for a total of 1,988 hours. The product water quality continued to deteriorate as membrane failure apparently worsened. An analysis performed after removal of the membranes suggests that the probable cause of failure was not related to fouling or use of sodium bisulfite, or of unknown constituents in the feedwater, but was more likely caused by some intrinsic failure of the membrane itself.

DESAL/FILMTEC CONTINUED STUDIES

Both manufacturers were disappointed with the results obtained during the first phase of the lime/RO low pressure membrane pilot tests. The FilmTec membrane was expected to produce an average flux of over 15 gal/ft^2-day, but as indicated by the data, after 2,100 hours of operation the normalized flux was only 9.57 gal/ft^2-day. The Desal membrane performance was less than had been anticipated in overall salt removal, and shortly after 1,000 hours the average rejection dropped dramatically due to the apparent membrane failure. Therefore, on June 22, both the FilmTec and Desal pilot plants were shut down and the first pressure vessel for each plant was reloaded. The Desal plant was reloaded with four membrane modules, each 25 inches long and containing approximately 60 ft^2 of active membrane surface per element, for a total of 240 ft^2. The FilmTec was loaded with five membrane modules, each containing 28 ft^2, for a total active membrane surface area of 140 ft^2. Figure 5 is a plot of the normalized flux rate of each of these two pressure vessels only. Product water quality for both vessels is shown as a function of operating time.

The two systems were operated under identical conditions, with one exception: Throughout the entire period, the Desal unit was operated with an average brine flow of about 4.5 gpm from the first pass element, while the FilmTec unit, due to downstream system constraints imposed by operation of the other five pressure vessels, had a brine flow from the first vessel of only 3.5 gpm. Slight variations in cleaning and sodium bisulfite addition are indicated by the event markers shown in Figure 5 (a summary of these events is presented in Table XI). A comparison of the Desal and FilmTec performance indicates that the initial normalized flux for both was approximately 17.5 gal/ft^2-day. Following a short increase in flux for the Desal unit, the flux gradually declined through the first 200 hours of operation. Performance of the system did not appear to be adversely affected by a 24-day shutdown (Event 1). Addition of 1,000 mg/l of sodium bisulfite (Event 2) was begun just prior to 200 hours and continued for the duration of the test. At 236 hours the plant was shut down for a brief period (Event 3), during which a small increase in normalized flux was observed (this same phenomenon was observed during the earlier shutdown and is typical for RO systems). Following this brief shutdown, the Desal flux rate stabilized, averaging approximately 13 gal/ft^2-day. Over this same period, rejection remained constant as product water quality varied from 30 to 50 μmhos, for an average rejection of 97.5%.

After 312 hours of operation (Event 4), a cleaning was attempted using a commercial solution known as King Lee 1000. This solution was applied in situ at a strength of 3% at 3.3 pH and a temperature of 100°F. Cleaning flow was maintained at 8 gpm for one hour. Very minor improvement in flux occurred after the cleaning. The King Lee 1000 cleaning solution is a low pH product generally used to clean inorganic scale precipitants, and since all earlier indications suggested biological fouling rather than inorganic scaling, the ineffectiveness of this cleaning solution was not surprising.

After 433 hours of operation (Event 5), the Desal system was cleaned for one hour with the 1-1-1 solution at 120°F with pH adjusted to 11. The flux rate improved significantly, from 13.12 to 22.70 gal/ft^2-day, an increase of 73%. After 24 hours the flux dropped to about 17 gal/ft^2-day and has remained fairly constant. The cleaning also appeared to affect salt rejection, which dropped to about 90% immediately after cleaning and rose to 93% after 24 hours. This is about 4% lower than the rejection level prior to cleaning.

By comparison, the reloaded FilmTec vessel No. 1 showed a flux decline over the first 225 hours, from about 17 gal/ft^2-day to 10.8. The unit was then cleaned (Event 2) with the 1-1-1 solution, and normalized flux increased to 13.6 gal/ft^2-day, or 22%. This improvement was relatively short-lived, however, and within 50 hours vessel output had declined to precleaning levels. After 278 hours of elapsed time (Event 3), the addition of 1,000 mg/l of sodium bisulfite for two hours a day was initiated.

Another cleaning (Event 5) was performed after 414 hours, and again flux was raised from 9.6 to 10.6 gal/ft^2-day, an improvement of about 10%, similar to the results observed for the Desal vessel. Since the addition of sodium bisulfite, the FilmTec unit appears to have reached an equilibrium, with the flux stabilized around 10 gal/ft^2-day. As previously discussed, the role of sodium bisulfite has not been determined. Another theory for the two systems appearing to reach an equilibrium at different flux rates is the difference in brine flow rates. It is believed that the principal foulants causing the initial flux decline are biological in nature and that at some point the rate of fouling reaches equilibrium with the velocity of flow through the system. The rate of deposit of materials on the membrane surface equals the rate at which other particles are sheared from the fouling layer. Thus at higher brine flow rates, this point of equilibrium would be reached at a higher flux because of greater velocity of flow through the elements. This theory is supported by the observed results since the Desal system has operated at higher feed rates. Recent extensive membrane fouling studies conducted by OCWD with the University of California at Irvine have verified the key role biological fouling plays in the observed flux decline.

RO MEMBRANE FOULING STUDIES

Because of the significant impact of membrane fouling on the economics of wastewater desalting, a brief discussion of recent studies[4] to determine the exact cause of the flux decline observed in the Orange County RO system has been included in this paper. RO membranes which have been in continuous operation for several months were removed and cut open and the surface of the membrane examined. Observation of the membrane surface area revealed that all membranes were uniformly coated with a darkly colored mucilaginous fouling substance. Analysis of scrapings indicated the material was approximately 90% water by weight. Of the dehydrated fouling material, approximately 90% by weight consisted of organic compounds which could be volatilized at 500°C. The remaining 10% was primarily inorganic in composition and consisted of calcium, phosphorus, sulfur and chlorine, as determined by conventional chemical analysis as well as energy dispersive X-ray microanalysis.

Approximately 15% to 30% of the dry weight of the fouling material consisted of protein, while up to 17% was found to be carbohydrate. Adenosine-5'-triphosphate (ATP) was readily detected in the fresh biofilm scrapings, indicating the presence of large numbers of viable microorganisms. Bacteriological plate counts using both high and low nutrient artificial growth media indicated approximately 5×10^7 to 5×10^8 colony forming units per gram of wet weight of the biofilm. Accumulation of radioactively labeled glucose by fragments of the intact biofilm layer indicated the bacteria associated with the RO membrane surface were metabolically active and potentially able to proliferate in situ. Microbial identification studies indicated that Acinetobacter and Flavobacterium were the major bacterial groups associated with the biofilm fouling layer on the feedwater surface of the RO membrane.

Direct observation of the biofilm using both scanning and transmission electron microscopy revealed that the fouling layer was composed primarily of large numbers of firmly attached bacterial cells which were in various stages of autolytic decay. The bacteria formed a contiguous layer measuring 10-20 microns in thickness on the feedwater surface of the RO membrane. Apparently healthy intact bacterial cells were found throughout the biofilm, surrounded by membranous material from autolysed cells. The bacteria were attached to the RO membrane or the biofilm surface by means of an extensive network of extracellular polymeric fibrils radiating outward from the individual cells. In a profile view, the biofilm exhibited a distinct multilaminar construction consisting of several individual layers of cellular debris and intact bacteria, compacted to varying degrees by the elevated hydrostatic pressure. The outermost several micrometers of the biofilm correspond with the most recently deposited layer, which was the least compressed of the individual lamelli.

More detailed investigations are now under way to determine the best way to either remove the biofilm or to prevent its growth on the surface of the membrane. As part of this work, the rate of biofilm development is being observed and various new cleaning solutions are to be tested to determine their ability to remove the biofilm from the membrane surface.

CONCLUSIONS

Based on the latest lime/RO low pressure pilot plant operation, the feasibility of this process has been demonstrated, and significant cost savings can be realized. Current wastewater demineralization costs at WF-21 are approximately \$819 per million gallons (MG). The current RO pretreatment train, which includes lime clarification, air stripping, recarbonation, filtration, and activated carbon adsorption/regeneration, costs an additional \$1,000 per MG. Conversion to the lime/RO process will eliminate air stripping, filtration, and activated carbon adsorption and regeneration. Based on current operating costs, this would amount to a cost saving of \$488/MG or almost one half the pretreatment cost.

A breakdown of the current wastewater demineralization cost (excluding pretreatment of the secondary effluent) is \$820/MG, as shown in Table XII. These costs were based on operation of the wastewater demineralization plant at 460 psig operating pressure and an average flux rate of 8 gal/ft^2-day. The reduction in operating pressure produced by the new composite type membranes from 460 to 250 psig will reduce power requirements by about 46% which, based on current electrical costs, would save about \$178/MG. It also appears that the low pressure TFC membrane can be operated at higher flux rates, in the range of 11-15 gal/ft^2-day. Taking the worst case of 11 gal/ft^2-day as compared to the 8 gal/ft^2-day rating for the existing cellulose acetate type membrane in the 5 mgd RO facility, this is an improvement of about 37.5% flux. Thus, for the same size plant, capital cost would be reduced by this amount. Using OCWD's 5 mgd amortized capital cost, this would result in a saving of another \$75/MG. Higher flux would also reduce the cost of some of the fixed operational costs such as operations labor and the maintenance contract. This would provide additional savings of \$65/MG.

In summary, the use of low pressure membranes in the lime/RO process appears to provide a comparable quality of water at a cost saving of \$809/MG over the present operating cost of OCWD's full scale 5 mgd RO system. In addition to these savings of more than 44%, it appears optimistic that a continuation of effort will determine the best way to mitigate fouling and subsequent flux decline, and that less expensive RO pretreatment trains will be developed to produce even larger cost savings in the future.

ACKNOWLEDGMENTS

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APPENDIX

Metric Conversions

million gallons per day (mgd) x 43.812 = liters per second (l/s)

pounds per square inch (psi) x 6.895 = kilonewtons per square meter (kN/m^2)

gallons per day (gpd) x 3.785 = liters per day (l/d)

gallons per square foot per day (gal/ft^2-day) x 0.4715 = milliliters per square meter per second (ml/m^2-s)

gallons per minute (gpm) x 63.08 = milliliters per second (ml/s)

square foot (ft^2) x 0.0929 = square meter (m^2)

inch x 2.54 = centimeter (cm)

million gallons (MG) x 3.785 = megaliter (Ml)

(°F-32) x 5/9 = centigrade (°C)

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3. D. G. Argo and R. G. Sudak, "Wastewater Demineralization by the lime/RO Process with Low Pressure Membrane," presented at the NWSIA Ninth Annual Conference, Washington, D.C., June 1981.

4. H. F. Ridgway, C. Justice, A. Kelly, B. H. Olson and D. G. Argo, "Biofouling of Reverse Osmosis Membranes at Water Factory 21: Chemical and Microbiological Characterization of the Fouling Layer," July 1981.

TABLE I

Typical Quality of WF-21 Lime Clarified Secondary Effluent*

Parameter	Unit	Effluent Concentration
EC	µmho	1589
pH		11.07
Turbidity	TU	1.04
Sodium	mg/l	225
Chloride	mg/l	261
Ammonia	mg/l	31.7
Organic Nitrogen	mg/l	1.59
Silica	mg/l	13.1
Phosphorus	mg/l	0.23
TOC	mg/l	11.4
COD	mg/l	32.2
Iron	µg/l	47.5
Total Coliform	#/100 ml	1.34

*Average from February 1, 1981 through July 30, 1981

TABLE II

FilmTec FT-30
Low Pressure Membrane Performance

January 29, 1981
Elapsed Time 2.0 hours

	1	2	3	4	5	6
Feed						
Flow, gpm	5.82	4.67	3.40	2.80	2.21	1.96
Concentration, µmhos	1700	2103	2855	3441	4338	5029
Permeate						
Flow, gpm	1.15	1.27	0.60	0.59	0.25	0.21
Flux, gal/ft^2-day	10.3	11.4	10.8	10.8	7.5	6.3
Active Membrane Area, ft^2	160	160	80	80	48	48
Concentration, µmhos	62	90	120	80	120	130
Brine						
Flow, gpm	4.67	3.40	2.80	2.21	1.96	1.75
Concentration, µmhos	2103	2855	3441	4338	5029	5616
Feed/Brine Average Rejection, %	96.3	95.7	95.7	97.6	97.2	97.4
Feed Pressure, psig	200	----	178	----	154	----

Total membrane area = 576 ft^2
Total product flow = 4.07 gpm
Average actual system flux = 10.17 gal/ft^2-day
Average normalized system flux = 12.91 gal/ft^2-day
Total product concentration = 70 µmhos
Rejection based on feed = 96%
Recovery =70%

Note: All data normalized to 250 psi at 77°F.

TABLE III

FilmTec FT-30
Low Pressure Membrane Performance

February 8, 1981
Elapsed Time 30 hours

	1	2	3	4	5	6
Feed						
Flow, gpm	4.8	3.8	2.7	2.1	1.6	1.35
Concentration, µmhos	1800	2265	3176	4073	5332	6309
Permeate						
Flow, gpm	1.0	1.1	0.6	0.5	0.25	0.23
Flux, gal/ft^2-day	9.6	9.9	10.6	9.3	7.2	6.9
Active Membrane Area, ft^2	160	160	80	80	48	48
Concentration, µmhos	30	27	36	43	52	88
Brine						
Flow, gpm	3.8	2.7	2.1	1.6	1.35	1.12
Concentration, µmhos	2265	3176	4073	5332	6309	7586
Feed/Brine Average Rejection, %	98.3	98.8	98.8	98.9	99.0	98.6
Feed Pressure, psig	250	----	237	----	224	----

Total membrane area = 576 ft^2
Total product flow = 3.75 gpm
Average actual system flux = 9.37 gal/ft^2-day
Average normalized system flux = 9.23 gal/ft^2-day
Total product concentration = 80 µmhos
Rejection based on feed = 95.6%
Recovery =78%

Note: All data normalized to 250 psi at 77°F.

TABLE IV

FilmTec FT-30 Major Events

Event No.	Elapsed Time (hrs)	Event
1	330	Removed and replaced all membrane elements in pressure vessel No. 1.
2	475	Cleaned membranes in situ with 1% solution of TSP, STP, EDTA (Solution 1-1-1) for 30 min. Solution pH adjusted to 11.0; temp. 120°F. Started feeding 20 mg/l chlorine 2 hrs/day.
3	565	Cleaned membranes in situ with 0.1% solution of Sanizyme (compound containing several enzymes including amylases, proteases, lipases, and cellulose) for 30 min., then with 1-1-1 same as in event 2.
4	630	Brine valve accidentally closed; unit operated at 100% recovery for 10 hours; scaling. Stopped feeding 20 mg/l chlorine 2 hrs/day.
5	700	Flushed unit with 1.5% solution of citric acid and repiped RO product water as feed to dissolve scale during next 150 hours.
6	856	Cleaned unit with 1-1-1 for one hour at 120°F and returned system to operation on lime clarified activated sludge effluent. Began feeding sodium bisulfite at 1,000 mg/l for two hours per day.
7	975	Cleaned membranes with 1-1-1 for 30 min. at 120°F.
8	997	Cleaned membranes with 1-1-1 for one hour at 120°F.
9	1,180	Cleaned membranes with 1-1-1 for one hour at 120°F.
10	1,202	Cleaned membranes with 1% sodium lauryl sulfate for one hour; pH 7.9, 120°F.
11	1,317	Cleaned membranes with 1-1-1 at 250 psi to increase brine flow to maximum for 20 min.

TABLE IV continued

Event No.	Elapsed Time (hrs)	Event
12	1,473	Cleaned membranes with 1-1-1 at 250 psi with 5 gpm brine flow for 30 min. Soaked membranes one hour in hot solution (120°F), then flushed with cold water.
13	1,940	Cleaned membranes with 1-1-1 at 250 psi with 4 gpm brine flow for one hour. Flushed with tap water for 10 min.
14	2,104	Cleaned membranes with 1-1-1 at 250 psi 5 gpm brine flow for one hour. Flushed with tap water for 10 min.

TABLE V

Effect of Cleaning Velocity on an Individual Four-Inch Diameter FT-30 Membrane

Operating Condition	Feed Pressure psig	Δp psig	Feed/Cleaning Flowrate, gpm	Product Flowrate gpm	Product Conductivity µmhos
Lime/RO feed	250	--	2.02	0.18	13
First cleaning	58	3.0	5.0	--	--
Lime/RO after 1st cleaning	250	--	2.34	0.24	10
Second cleaning	56	11.0	10.0	--	--
Lime/RO after 2nd cleaning	250	--	2.21	0.25	10
Third cleaning	56	19.0	15.0	--	--
Lime/RO after 3rd cleaning	250	--	2.28	0.28	15
Fourth cleaning	56	21.0	17.5	--	--
Lime/RO after 4th cleaning	250	--	2.61	0.30	11

TABLE VI

Effect of 5 mg/l Free Chlorine on the Performance of FilmTec FT-30 Low Pressure Membrane

	Before Exposure to Cl_2	After 48 hrs. Exposure to Cl_2
Feed pressure, psig	45	45
Feed Conductivity, μmhos	490	450
Product Conductivity, μmhos	20	16
Product Flow, gpm	0.020	0.028

TABLE VII

FilmTec FT-30
Low Pressure Membrane Performance

June 5, 1981
Elapsed Time 2,106 hours

	1	2	3	4	5	6
Feed						
Flow, gpm	5.6	4.1	2.9	2.19	1.77	1.56
Concentration, μmhos	2100	2860	4030	5325	6574	7449
Permeate						
Flow, gpm	1.5	1.2	0.71	0.42	0.21	0.21
Flux, gal/ft^2-day	13.5	10.8	12.7	7.56	6.30	6.30
Active Membrane Area, ft^2	160	160	80	80	48	48
Concentration, μmhos	20	32	34	58	67	100
Brine						
Flow, gpm	4.1	2.9	2.19	1.77	1.56	1.35
Concentration, μmhos	2860	4030	5325	6574	7449	8591
Feed/Brine Average Rejection, %	99	98	99	98	98	98
Feed Pressure, psig	250	----	230	----	214	----

Total membrane area = 576 ft^2
Total product flow = 4.26 gpm
Average actual system flux = 10.65 gal/ft^2-day
Average normalized system flux = 9.57 gal/ft^2-day
Total product concentration = 36 μmhos
Rejection based on feed = 98.3%
Recovery =76%

Note: All data normalized to 250 psi at 77°F.

TABLE VIII

FilmTec FT-30
Typical Water Quality Performance*

Constituent	Feed mg/l	Permeate mg/l	Rejection Percent
Sodium	230	7	97
Chloride	261	7	97
Sulfate	500	8	98
Calcium	105	<1	99
COD	31	<1	99
TOC	11	0.9	92
Ammonia	35	1.0	97

*Average quality over 2,000 hours of operation

TABLE IX

Desal I
Low Pressure Membrane Performance

January 29, 1981
Elapsed Time 2.0 hours

	1	2	3	4	5	6
Feed						
Flow, gpm	11.7	8.24	5.09	4.03	3.25	2.73
Concentration, µmhos	1600	2220	3414	4219	5092	5864
Permeate						
Flow, gpm	3.5	3.15	1.06	0.78	0.52	0.33
Flux, gal/ft^2-day	21.0	18.9	12.7	9.36	9.36	5.94
Active Membrane Area, ft^2	240	240	120	120	80	80
Concentration, µmhos	140	290	350	580	640	690
Brine						
Flow, gpm	8.24	5.09	4.03	3.25	2.73	2.40
Concentration, µmhos	2220	3414	4219	5092	5864	6575
Feed/Brine Average Rejection, %	91	86	89	86	87	88
Feed Pressure, psig	200	----	167	----	137	----

Total membrane area = 880 ft^2
Total product flow = 9.34 gpm
Average actual system flux = 15.28 gal/ft^2-day
Average normalized system flux = 19.4 gal/ft^2-day
Total product concentration = 280 µmhos
Rejection based on feed = 82.5%
Recovery = 79.6%

Note: All data normalized to 250 psi at 77°F.

TABLE X

Desal I
Typical Water Quality Performance*

Constituent	Feed mg/l	Permeate mg/l	Rejection Percent
Sodium	230	39	83
Chloride	261	74	72
Sulfate	500	5	99
Calcium	105	<1.5	99
COD	31	<1.5	>95
TOC	11	0.8	93
Ammonia	35	4.4	87

*Average removal during first 1,000 hours of operation only

TABLE XI

Major Events Which Occurred During Operation of Desal I and FT-30 Pilot Lime/RO Plants

Desal I	Event No.	FilmTec FT-30
Plant shut down for 24 days	1	Plant shut down for 24 days
Began adding 1,000 mg/l sodium bisulfite 2 hrs/day	2	Cleaned with 1-1-1 at pH 11.0 and 120°F
Plant shut down for 24 hrs	3	Began adding 1,000 mg/l sodium bisulfite 2 hrs/day
Cleaned with King Lee 1000	4	Plant shut down for 24 hrs
Cleaned with 1-1-1 at pH 11.0 and 120°F	5	Cleaned with 1-1-1 at pH 11.0 and 120°F

TABLE XII

Operating and Capital Costs WF-21 RO Demineralization

		$/MG
Capital		208.87
Operating		610.77
Operations labor	37.57	
Electricity	390.80	
H_2SO_4	18.21	
Chlorine	0.77	
SHMP	26.51	
Maint. contract	136.32	
Gas	0.59	
TOTAL		819.64

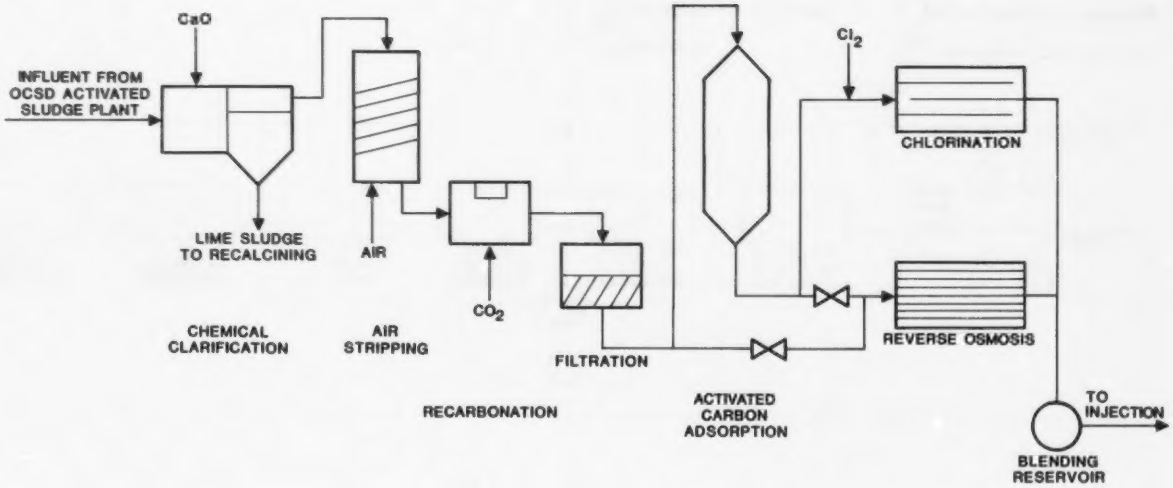
CaO
INFLUENT FROM OCSD ACTIVATED SLUDGE PLANT
LIME SLUDGE TO RECALCINING
AIR
CO_2
Cl_2
CHLORINATION
REVERSE OSMOSIS
TO INJECTION
BLENDING RESERVOIR
CHEMICAL CLARIFICATION
AIR STRIPPING
RECARBONATION
FILTRATION
ACTIVATED CARBON ADSORPTION

Figure 1. Process Configuration of Water Factory 21

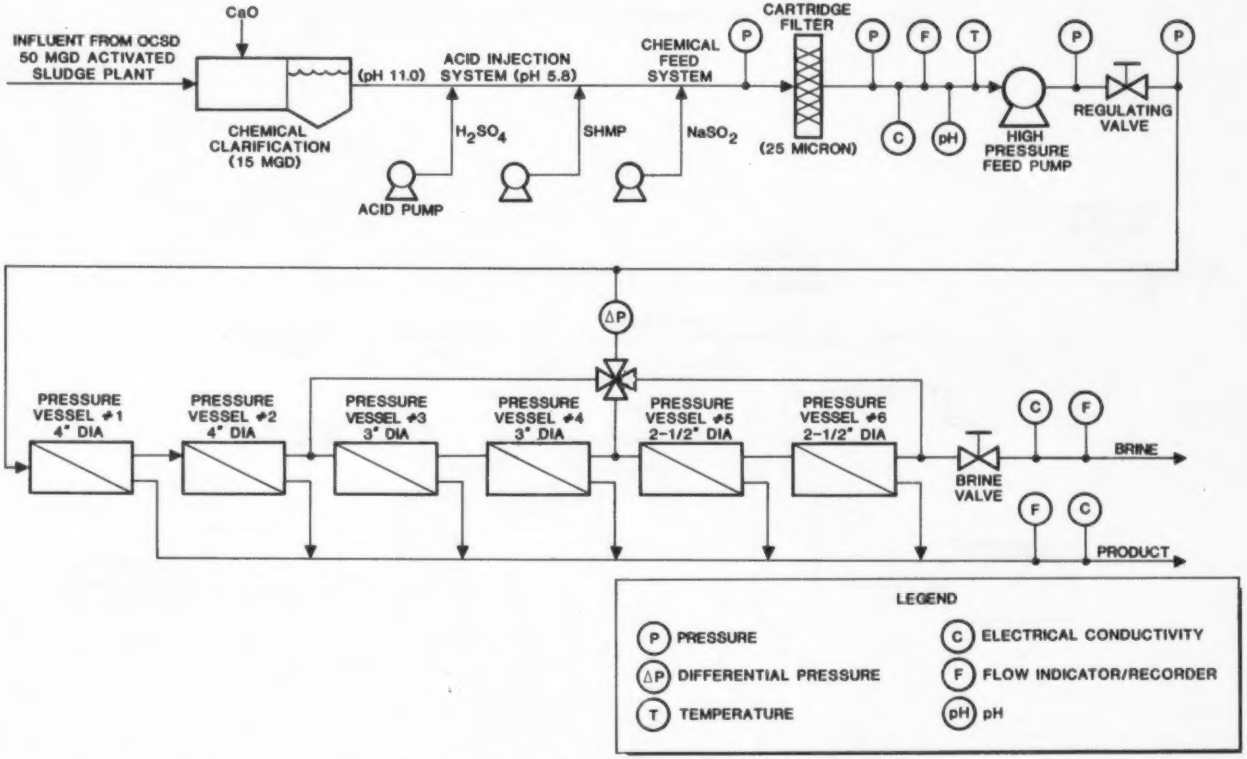
INFLUENT FROM OCSD
50 MGD ACTIVATED
SLUDGE PLANT
CaO
CHEMICAL
CLARIFICATION
(15 MGD)
(pH 11.0)
ACID INJECTION
SYSTEM (pH 5.8)
H_2SO_4
ACID PUMP
SHMP
CHEMICAL
FEED
SYSTEM
$NaSO_2$
P
CARTRIDGE
FILTER
(25 MICRON)
P
F
T
C
pH
HIGH
PRESSURE
FEED PUMP
P
REGULATING
VALVE
P
ΔP
PRESSURE
VESSEL #1
4" DIA
PRESSURE
VESSEL #2
4" DIA
PRESSURE
VESSEL #3
3" DIA
PRESSURE
VESSEL #4
3" DIA
PRESSURE
VESSEL #5
2-1/2" DIA
PRESSURE
VESSEL #6
2-1/2" DIA
BRINE
VALVE
C
F
BRINE
F
C
PRODUCT
LEGEND
P PRESSURE
ΔP DIFFERENTIAL PRESSURE
T TEMPERATURE
C ELECTRICAL CONDUCTIVITY
F FLOW INDICATOR/RECORDER
pH pH

Figure 2. Process Configuration of Lime/RO Process with 10,000 gpd RO Pilot Plant

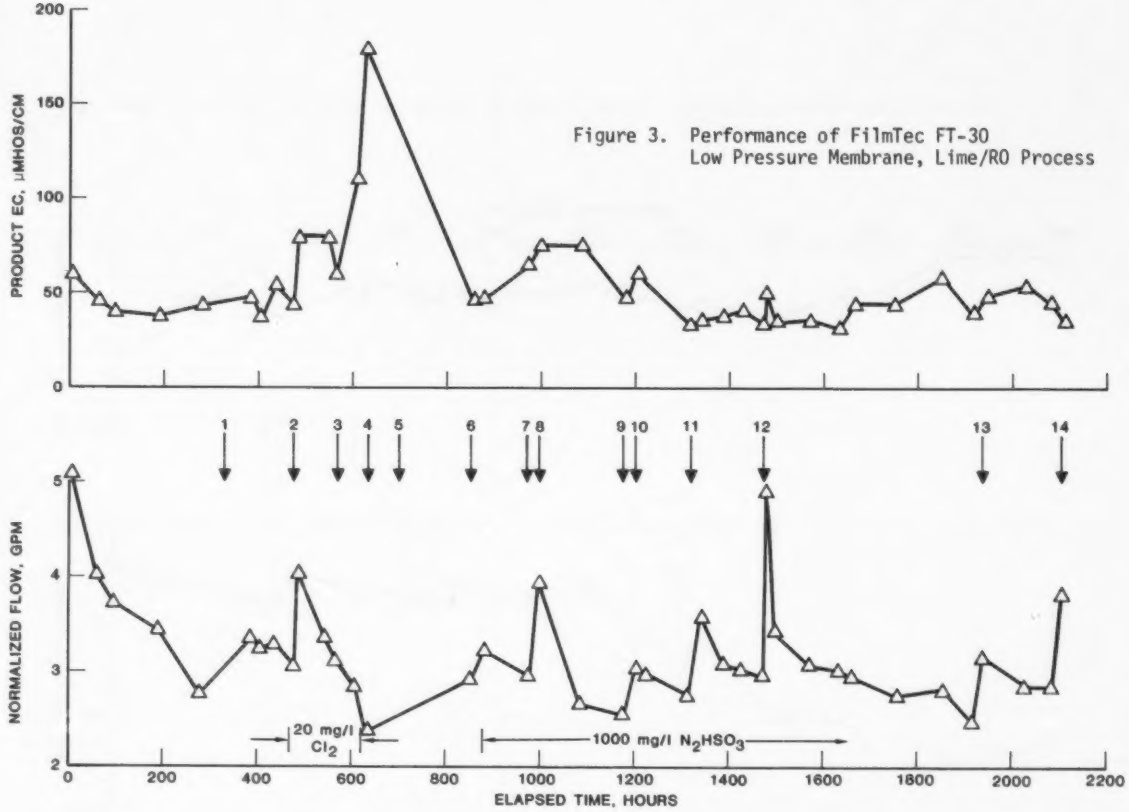

Figure 3. Performance of FilmTec FT-30
Low Pressure Membrane, Lime/RO Process

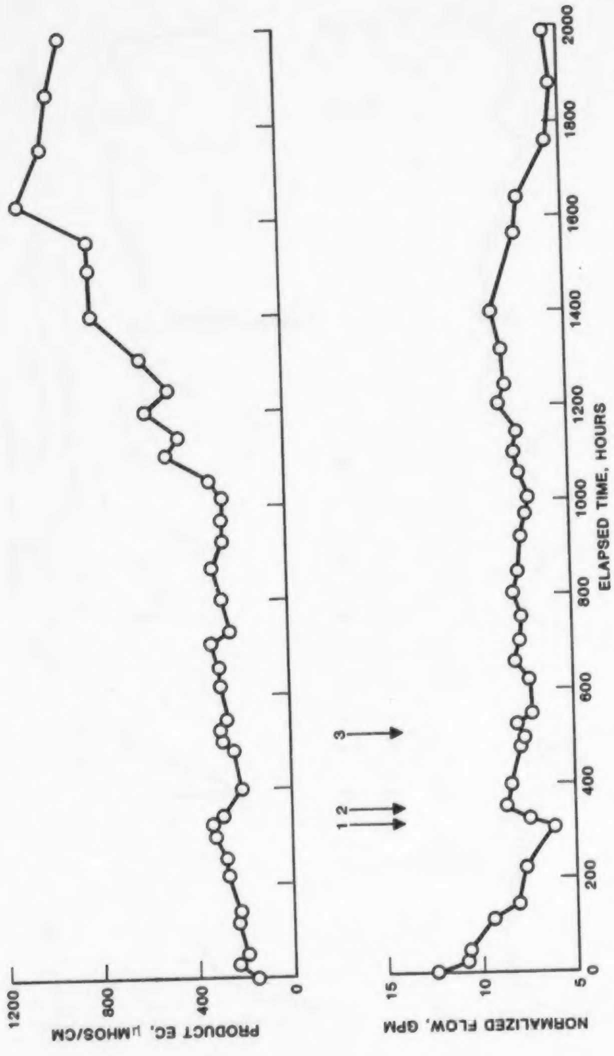

Figure 4. Performance of Desal I Low Pressure Membrane, Lime/RO Process

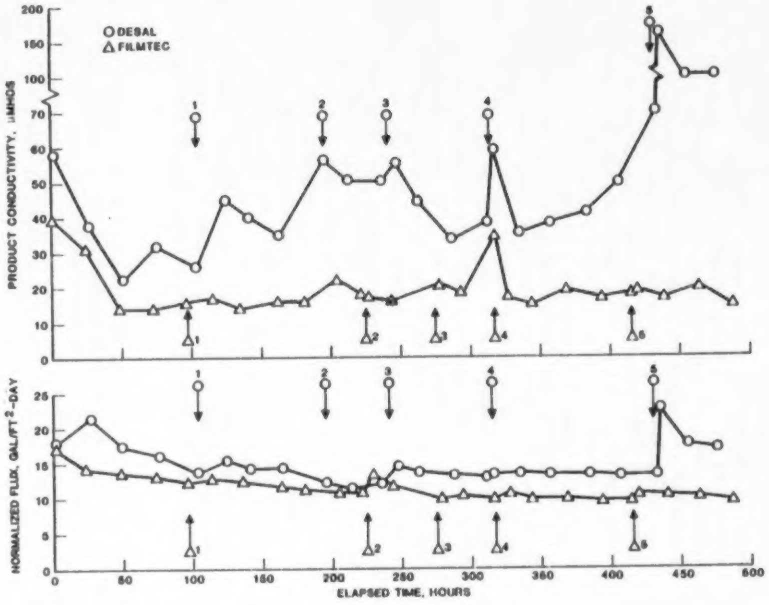

Figure 5. Comparison of FT-30 with Desal I Low Pressure Membrane, Lime/RO Process Data Shown for Pressure Vessel No. 1 only

IRVINE RANCH WATER DISTRICT: RECLAMATION RENEWAL

Ronald E. Young
Director of Engineering and Planning
4201 Campus Drive
Irvine, California 92715

The Irvine Ranch Water District (IRWD) is renewing its pioneering efforts at development of wastewater reclamation facilities, including a dual irrigation water distribution system, using modern planning techniques and unique engineering practices. The IRWD first pioneered the use of reclaimed water in the mid 60's by placing effluent on nearby agricultural lands owned by The Irvine Company (TIC). Historically, the IRWD was formed in 1961 as a California Water District and did not get into the wastewater treatment and disposal business until 1965 when State legislation was passed to allow such responsibilities. As soon as this was inacted, the IRWD faced the age old question that all wastewater entities must answer; "which is the best method of treatment and disposal of the effluent in our local jurisdiction?" At that time, in the mid 60's, the Irvine community was being planned by TIC, and a joint effort was made to coordinate the wastewater planning, and community planning through the efforts with TIC. At that time, the land use planning appeared to show a high agricultural use of the Irvine Ranch with a modest residential development. With that in mind, it was possible to forecast very high agricultural water demands and match wastewater reclamation as a potential source. The decision for disposal by reclamation was made within the first water resources master planning efforts. Here a comparison was made between the cost effectiveness of reclaiming the water to the then current standards of disposing of the effluent into an ocean outfall or stream. At that time, the cost comparison favored reclamation. This alternative was presented to the water quality agencies in California. They recommended that the alternate include backup capacity such that if discharge requirements were not met, an ocean outfall or other disposal system might be available. Planning had been undertaken by the neighboring Orange County Sanitation Districts to build a treatment plant and a new deep ocean outfall. IRWD accepted the recommendation and purchased 15 MGD capacity in the ocean outfall only, but not the treatment process of the Orange County Sanitation Districts.

During subsequent periodic planning processes, the IRWD disposal plan evolved around TIC modifying its development plans by increasing its urban land uses and decreasing its agricultural holdings. The land use and water planning continued through 1972 when a water resources master plan was completed. This included importing water to the Irvine area for domestic purposes as well as constructing conveyance facilities to bring untreated water to the area for agricultural purposes. Interim amendments have been made to these plans, but to date, no entire revision has been completed. Based on actual irrigation patterns and changes in crops and landscaping applications, current projections show that in the IRWD service area between 18 and 23 MGD of reclaimed water could be used on an annual basis. This is about 15 MGD less than projected ultimate flow, either great planning or a serendipidous coincident. This necessitates about 15 MGD of absolute disposal outside the Irvine

Ranch. The 15 MGD could be disposed of through the IRWD capacity in Orange County Sanitation Districts' outfall or through other reclamation projects outside the IRWD. One such outside project would be the Orange County Water District Green Acres project. An IRWD connection to their distribution system could be made which would supply an additional source to their area.

Since 1967 when about 300 acre feet of treatment plant effluent was recycled, until now, the Irvine Ranch has disposed of most nearly all of its effluent through either agricultural or landscape irrigation. During this 14 day period, the District has gone through numerous experiences relating to the operational aspects of a reclamation system. Several areas of operating concern are worthy of sharing since a reclaimed water system has many similarities to a domestic water distribution system, but also has many differences. These include a discussion of key system differences, how system interconnections play a part in our day-to-day life, how energy and drought have effected us, and thoughts on reservoirs and actual changed conditions depending on who the final user might be as well as some of the reclaimed water monitoring steps that were required to be implemented by local regulatory agencies.

Reflecting on the differences between a domestic water supply and a reclaimed water distribution system, some engineering concepts are worthy of a little extra thought. First, the source for the reclaimed water system, the wastewater treatment plant, is usually located at the lowest geographical spot within a service area. This is simply because most wastewater collection systems are designed to use gravity, and then many times dispose of their effluent into a lower watershed tributary. This undesirable requirement of pumping can create a situation that takes careful analysis of the wastewater disposal. It often requires multiple pumping stages in order to cover the higher elevations within a distribution area.

The second interesting point is the seasonal demand cycle created by irrigation. One area that the District has cooperated in with the local health department is in trying to promote landscape watering in unsupervised areas during times when there would be a minimum of public contact. This basically relates to watering between 9:00 p.m. and 6:00 a.m. This doesn't match the wastewater production curve and, if fact, creates a high demand during the late evening hours on the reclaimed water system when wastewater production is usually low. At IRWD, peak hour ratios for reclaimed water is in excess of three times the annual average while the domestic system peak ratio is about 2.25. Another complicating factor is analyzing demand that has been empirically determined at IRWD is that of fluctuations over a very short period of time, say, in the order of five to ten minutes. These fluctuations appear to be related to the operating mode of using automatic timer clocks for the landscaping irrigation areas. The normal watering cycles used by the irrigators is between six and fifteen minutes on, and then off until the next cycle. An example are the city's streetscapes which are watered on five minute cycles with two cycles each evening, four evenings per week. The interesting aspect here that is we are attempting to analyze is if this six to eight minute cycle could approach the system's natural frequency and actually cause an amplification of the pressure conditions in the distribution system to the point of physically affecting the system. Solutions that IRWD is looking towards with regard to solving some of these potential and real fluctuations of flow and pressures throughout the distribution system include an equalizing of the demand as much as possible. These include advance scheduling of agricultural use of waters and requiring landscape architects to design their water systems with longer watering periods and watering smaller areas and using smaller flows for each individual site or tract and installing an operational reservoir to dampen the fluctuations.

An occasional question is raised regarding metering of reclaimed water. The IRWD has avoided problems by locating meters in conventional parkways with easy access for meter readers and maintenance people. One suggestion that is being implemented is that of placing low maintenance strainers in front of the meter to protect it from occasional debris which can come from the system. An example of this type of strainer would be a Hayward Model No. 72.

Another important concern is that of domestic and reclaimed water interconnections. The first question that arises is how could such a thing happen, and why? The solutions then is what is an acceptable way to deal with this type of circumstance. This usually takes place where domestic water is supplied into a District reclaimed water irrigation system area. This is often done in areas of development where the reclaimed water is not yet available since the backbone or large distribution piping has not been completed before reclaimed water is available. This requires the temporary use of domestic water for irrigation purposes. Another cause for this type of interconnection was experienced during drought conditions. During a drought, attempts are being made to conserve domestic water thereby reducing the amount of wastewater. The reclamation system gets a double wammy with less of a supply and greater demand. So in some instances when their demand could not be met, it becomes necessary to take users or customers off the reclaimed water system and place them on a domestic water system.

In looking at the former interconnections, these are usually removed in a permanent fashion, going underground and capping, blind flanging, and thrust blocking the domestic water system and removing the backflow preventer, and perhaps changing meters for the reclaimed water system. In the second instance where it is anticipated that the situation may repeat itself, or in the case of a larger user who could drawdown system pressures and still not being able to get his flow of water in a shortage period, a piping network above ground is established. This would include blind flanges that can be removed so it is quite clear and mistake proof with only one water supply system being maintained at a time, i.e. leaving the extra space in the domestic side which must provide a backflow preventer and having a shorter space on the reclaimed water side so that the piping can not be mistaken in either direction. It's a good piece of planning if this condition can be anticipated so that in areas throughout the system, whether it be a single large user such as a golf course or perhaps a large developed area, the piping can be put in place during the planning stage. It can be in a vault or roadway or above ground in a landscaped area where the demand can be significantly reduced by switching to a domestic water system. This flexibility required another obvious caveat in the supplier's rules and regulations, that the end user be required to pay the appropriate rates for the source of water, being higher with domestic water and that the switch over and source of water be made at the absolute discretion of the serving agency. On the customer's side it should also be included in the regulations or agreement that as soon as the lesser cost reclaimed water is available that the return to prior service should be switched back.

Another area of concern is that of energy conservation of energy use in fulfilling the requirements of a reclaimed water distribution system. As I noted earlier, these systems tend to be largely pump systems and as such they are very high energy users. This coupled with the trend of power utilities to adopt Time Of Use (TOU) electrical energy pricing has made it important to consider the cost/benefit of storage of reclaimed water to meet the peak demands. As you might have guessed, the peak demands of the reclaimed water system at IRWD do not coincide with the peak production periods nor do they coincide with the lesser TOU options. One way that IRWD has been able to reduce pumping costs has been by using natural gas combustion engines to pump the water during the peak electrical cost demand times during daylight hours. Then, during the late evening through early morning hours, the puming is switched to electric driven pumps which are able to take advantage of the less expensive power during the high demand periods during the night.

The aspect of storage versus pumping has been able to be optimized by IRWD in that our treatment facilities have a flow equalization basin between the primary and secondary treatment phases. With careful manipulation of the equalization basin, the plant operators have been able to better match the demand curve by actually storing our primary effluent until the evening demands are felt and then releasing subsequent secondary and tertiary treatment for distribution in the reclaimed water system. This manipulation is made possible by the fact that we have excess equalization capacity available because flows are just slightly more than one half of the design flow rate.

Another unique circumstance of a reclaimed water system is that storage, whether operational or seasonal, can often be in open reservoirs. This open reservoir concept is one that is often promoted, not only from the cost aspects, but also from a dual use advantage. The dual use would be that of recreation depending on the quality of the water. One of the challenges that came with the territory at IRWD and is probably similar to others is that open reservoirs were inherited by the District from local agricultural uses. This occurred as the development patterns reduced the watering needs of agriculture. In IRWD they were able to trade their reservoirs for future reclaimed water. The agricultural reservoirs have in effect made incremental amounts of seasonal storage available early, but at the same time, have come with some of the problems that are associated with earth filled dams. These include the expense of maintenance and repairs that are brought about by heavy rains and overflowing spillways. Another facet in earthquake prone areas are the requirement for seismic analysis and continued geotechnical monitoring programs. Some of our recreational uses include the enhancement of the game of golf with lakes as well as hunting and fishing recreation in some of our more remote facilities. While fishing provides positive recreational aspects, an important point is that this also has to be considered in the engineering of the reservoir outlet structure and subsequent distribution system. Historically, the irrigation of farm lands has evolved depending on the amount of water conservation and costs to implement different systems from surface spreading to spray type application to the now often used drip irrigation. As these different systems evolved, their also evolved the need to have water with less and less particle matter to be able to be transmitted to the smaller control orifices. This brings us back to the question of reservoir outlet structure which should have the capability to be kept clear of debris, whether it be from runoff during rain storms or from fish which can cause problems in the distribution system.

A very important aspect in the day-to-day operations of a reclaimed water system is that of monitoring the facilities. In our case, monitoring takes into account a varied number of activities not related to wastewater treatment plant itself, but strictly to the operation as it relates to the end users. The purpose for this monitoring program in which IRWD has four full time technicians is twofold. First, is that of assuring the regulating authorities of the public health aspects of the use of reclaimed water and second, the District's own advantage of seeing that the water is properly used by promoting the best use possible of this valuable resource. The IRWD measures physical parameters such as the total flow into the distribution system and matches that with metered sales and other uses of the reclaimed water to achieve a water balance and also account for revenues for budgeting purposes. The system is also interdispersed with some twelve pressure recording stations which are currently monitored continuously to indicate potential problems and level of service that is applied.

A design is underway which will provide the IRWD with a computer based telemetry system covering the reclaimed and domestic water distribution and wastewater treatment facilities to more accurately monitor the systems and make more readily available the physical data about the operation of the system. The quality of the reclaimed water is measured to assure that the public health safety levels are being maintained throughout the system. In the California law, the requirement is to meet a coliform count through a perscribed treatment process at the point of discharge and not at the point of application. This date is monitored, and the same coliform chlorine residual and temperature tests are also made at five distribution points on different days each week. As a part of obtaining the NPDES permit for use and production of reclaimed water, the IRWD promulgated a Board adopted set of rules and regulations. It also adopted a standard specification for reclaimed water application. These two sets of rules formulate the local laws under which water reclamation is carried out. They provide one of the best sources of information that staff uses to monitor the actual implementation of the distribution facilities. With the landscape applications, the individual developer will bring his plans, usually completed by a landscape architect, to the District for review and plan check. Plans are checked to see that they meet the standard specifications and include the most efficient hardware with the sprinkler patterns laid out to minimize runoff and over spray and will be basically kept in the confines of the landscape area. To follow-up on the plan check process, the monitoring section will then inspect the construction for compliance with the approved plans. Once the system is complete, the same inspection group does an acceptance test based on the actual watering application and how a system is intended to be operated. Subsequently, after the system is in place, the same monitoring crew has the responsibility to visually inspect all the reclaimed water system for amount of time, and cycles which are placed on the timer box controlling the application of water and monitor for the potential problems of excessive runoff and over watering. As in the case with most things, it can not be over emphasized that the advantage of having a good landscape architect develop plans that can prevent future problems that occur in this kind of system.

As I noted earlier, the IRWD is continuing to pioneer efforts in the reclamation field. Currently underway are several studies that are renewing this effort and hopefully clearing the way for others to apply similar new techniques. One of these projects is the seasonal storage of our reclaimed water in underground aquifers of the Irvine sub-basin. This study has been ongoing in the feasibility stage for approximately one year. We have reached a point where we will be going through a public hearing and comment process before initiating, hopefully, a test program consisting of two injection and extraction wells. The entire concept is one of extracting the water from the groundwater basin during the peak summer demand months which comprise of a seven month season at Irvine and store the produced water during the five month winter season. This system is one where all the reclaimed water would be removed and used each year. This type of system is possible for several reasons. One being that the water quality in the groundwater basin where the storage project will take place is of a lower quality than the reclaimed water. Second is that the groundwater basin is currently being used minimally for domestic purposes and all these domestic uses can be removed and put onto the IRWD domestic water system. Third, is the aspect that the aquifer storage appears to be a less expensive alternative than surface storage behind an earth filled reservoir. A test program will hopefully begin this winter to characterize more specifically the aquifer and the ability to obtain storage as well as a thorough investigation into the ability to control the water so that all placed water is in fact actually removed in this put and take system.

Another two part project is currently under. The first part is not terribly unique as it consists of putting our reclaimed water pumping and distribution system into a dynamic computerized model so that the engineering of the distribution system can be analyzed for flow and pressure conditions throughout the system. The second part, which is an outgrowth of this first network model, is to extrapolate the future network and have it modeled by the computer for demand and pipe size flow and pressures. We will use this information in a linear programming model to consider the costs of energy, the costs of alternate supplies, sources of water, the cost of treatment, the various system needs as this system expands to produce an optimal decision tree on how to expand the system, what facilities will be required and how this affects the end cost to our users. The linear programming technique is not new and is used extensively in franchise and manufacturing business applications where parts are being distributed to various assembly plants and brought back together to assemble full units. The application of these principles to analyze the best source of water for the various parts of the system balancing agricultural water versus reclaimed water in our dual distribution system,we think,is quite unique. Another study underway with our neighboring Orange County Water District is the potential for joining together the IRWD system with the Green Acres project to distribute reclaimed water on a subregional basis.

This presentation outlines where the IRWD has come from in establishing and continuing growth in the reclaimed water system and the ideas and future work that is being carried out to get the best use out of our existing and future water systems. The linear programming model in analyzing different options will basically be doing a balancing act in looking at the dual distribution system and making comparisons as to the cost effectiveness of replacing reclaimed water with domestic water or replacing reclaimed water with untreated water. In the former instance, the cost effectiveness will be measured by comparing the reclamation system cost which would consist of the costs of teriary treatment, delivering or pumping cost and the cost of installing the dual distribution infrastructure to the various tracts. In order to justify reclamation this cost will have to be less than the alternative of disposing of the effluent and taking into account the purchase price of domestic water plus some small costs for upsizing the domestic water system to handle the irrigation costs. The second alternative available, substituting untreated water which is available from the State Water Project in Northern California or Colorado River water, will be evaluated comparing the costs of tertiary treatment for reclamation and the pumping costs to distribute the water, but not counting the dual distribution piping as untreated water would still require segregation from the domestic water system. Again, the comparison would be made to the cost of purchasing the untreated water and the cost of disposal of that portion of the IRWD effluent. The dynamics of this program are looking at today's costs and then expanding the system in the future and continuing to compare those costs and considering the energy and water cost escalation factors to make comparisons in the computer model. In looking at the overall benefit of our reclamation program, it takes on a significant impact in light of the fact the combination of the Metropolitan Water District of Southern California has contracts with the State Water Project and the reduction of its allocation of water from the Colorado River forecasts shortages of water in the not too distant future, especially if the passage of California State Bill 200 allowing the construction of the Peripheral Canal and other facilities to bring more Northern California water to Southern California is not passed. In the drought or dry year scenario when water isn't available, it becomes very appropriate to compare the costs of reclamation to the cost of developing the next source of available water and essentially those costs, whether it will be simply capital costs far above $500 an acre foot for new water or the avoided cost of energy for pumping these long distant sources of supply to Southern California which could equate to an excess of $300 per acre foot. This may all have a secondary importance if the true shortage occurs and the agricultural users have to give up their water for the higher domestic use. In this instance, it becomes a market determination on the agricultural value of the food crops that are produced and the business decision on rate of return for the operations considering the increased costs for water.

While IRWD is comparing its future of reclamation, the Orange and Los Angeles Counties Water Reuse Study are addressing specific funding mechanisms to apply equity to local agencies by funding local projects as they contribute to increasing regional water supplies. These concepts are being discussed at another talk later in the conference.

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MUNICIPAL WASTEWATER (RAW SEWAGE) RECYCLING AT THE CITY OF SAN DIEGO, CALIFORNIA 1964 - 1980

RICHARD W. KING
Water Utilities Department
Director
City of San Diego, CA

W. M. CONN
Senior Treatment Plant Supervisor
Metro Wastewater Division
City of San Diego, CA

INTRODUCTION

The City of San Diego is located in a semiarid area of Southern California. Ample water is now available from the Colorado River and the Northern California waters. These supplies will fall short of the needs projected into the year 2000. Wastewater recycle in Southern California is now limited to ground basin recharge and limited legal agriculture - ornamental - landscape use. The San Diego City Water Utilities Department is a combined potable water supply and wastewater management unit. An informed City Council and Management considers it a necessity to research advanced sources of water reclamation and use. This paper describes in brief the period from 1964 to date: Direct raw sewage reclamation to boiler feedwater by reverse osmosis [1]; The use of an autocontrolled 20,000 gpd (75.7 m^3/d) raw sewage up graded for sod irrigation at a large athletic stadium; [1] study comparison of tubular ultrafilters for pretreatment of raw sewage prior to spiral wound reverse osmosis [2]; and the design for the installation of a 100,000 gpd ultrafilter (378.5 M^3/d) pretreatment for a 100,000 gpd (378.5 M^3/d) spiral wound reverse osmosis unit. [4] These units will be operated on reclamation of raw sewage (direct) and reclamation of wastewater from an aquaculture processed wastewater (hyacinths-treatment). A small (113.6 M^3/d) aquaculture will be in service in September 1981 to supply aquaculture (hyacinths) treated water to the membrane systems. A 1.0 MGD (3.7854×10^3 M^3/d) aquaculture (hyacinths) California State sponsored treatment plant will be built in 1982. [5] When this larger aquaculture plant is in service, the effluent will be treated by membrane processes. The ultrafilter and reverse osmosis treated effluent will be treated by ozone followed by granular activated carbon; and disinfected with ozone (and/or free radical hydroxyl activation). All of the effluent will be used for the San Diego River recharge and/or returned to the trunk sewers. An ultimate goal in the future is potable reuse.

BACKGROUND

In 1964, the City of San Diego began a series of reverse osmosis (cellulose acetate) membrane experiements on primary treated raw sewage effluent. The product was to be used for low pressure boilers for heating digesters. The experiments were started on early designed spiral-wound R/O modules. Soon it was discovered that more than primary treatment would be required. Local manufacturers of the membranes tried approaching the problem of plugging by increasing the spacers in the spiral module. Soon the limit of practical space sizes was realized. The next approach: coagulation and filtration (diatomaceous earth) of the primary sewage soon led to more and more pre-treatment.

At this point in time, tubular reverse osmosis modules of cellulose acetate membranes became available. This same period of time developed an empirical, practical, city testing program on wastewater reuse. Raw, 40 mesh screened, sewage would be tested on tubular R/O membranes without any farther pretreatment. 1964-1970 continued experiments in different manufactured tubular R/O systems led to a test plant for boiler feed water. A 20,000 gpd (75.7 M^3/d raw feed) pilot plant was designed, built and placed on stream at the City's wastewater treatment plant. The unit was an automated two stages of reverse osmosis tubular membrane modules. The plant produced 16,000 gpd (60.6 M^3d) of high purity boiler feed water from raw sewage at 70% recovery. Total dissolved salts removal averaged better than 95%. This removal was from an average raw influent of 2,000 ppm T.D.S. to less than 400 ppm T.D.S. in the product. Minerals and alkaline earths as well as nitrogen, phosphate, and sulfate removal rate were as high as 98%. The phosphate average 0.5 ppm from a raw sewage containing 30 - 40 ppm as PO_4. The product water was fed to two 10,000 gpd (38.M^3/d) boilers. The product still contained 0.1 to 0.3 ppm dissolved hydrogen sulfide; 0-5 ppm C.O.D.; 0.1 to 0.5 PO_4; 0-5 ppm nitrogen as NO_3; and 5-10 ppm total hardness as $CaCO_3$; detergents, as MBAS varied from a trace to 0.5 ppm. The boilers operated well; no foaming; no dissolved oxygen, low maintained solids.

Problems: The tubular unit had good membrane life; no biological degradation of cellulose acetate. A cleaning and precoat technique allowed 8 hour runs between cleaning cycles. The centrifugal pumps supplying the needed pressure of 500 and 600 psi did exhibit wear from abrasion. This was managed by preventive overhaul maintenance.

Results: The direct recovery of a boiler feed water from raw sewage operated from 1969 to 1975. In 1975, the pilot plant was moved to a location farther up stream for a more typical domestic sewage application. The site chosen up stream was on a 54" trunk sewer servicing the east half of the Metropolitan District. This San Diego Stadium site on the trunk sewer allowed a direct use of low mineral content product water on sod-farming (grass-infield to major league ball park). San Diego's tap water contains total dissolve solids from Colorado River water at 800 to 1000 ppm. The sod farm needed lower T.D.S. The pilot R/O plant produced 16-17,000 gpd (60.6 M^3/d) of high quality water (less than 400 ppm T.D.S.) direct from raw sewage ranging from 1300 ppm to 1500 ppm T.D.S. The product met all state discharge and reuse requirements for sod farming.

Results: Direct reverse osmosis (tubular) of raw sewage will produce a usuable irrigation water for ornmental crops. The pilot plant operated at a high cost due to the small size and subsequent engergy cost increases. Virus work by a California State sponsored study demonstrated the product water to be viral free [3]. This tubular R/O pilot study showed that a more economical membrane module approach is needed to reduce energy costs.

Ultrafiltration prior to spiral wound reverse osmosis was examined on raw sewage in 1980 - 1981. The goal was to reduce the power costs needed for membrane demineralization of raw sewage, and to select one ultrafiltration manufactured type. The City of San Diego has acquired a 100,000 gpd (378.5 M^3/d) spiral wound R/O unit. Spiral R/O has been chosen to replace the highly successful tubular unit for efficiency. Spiral units cannot handle suspended solids in raw sewage. Ultrafiltration using tubular units is chosen as the pretreatment for spiral R/O. Ultrafiltration separates from raw sewage (previous screened to 40-60 mesh) suspended solids; large molecules including protein, grease and oils. Moderate pressure; (therefore), lower energy is used to do the separation. Tubular units were chosen because of previous experience in tubular R/O use for over a decade on direct raw sewage. Four ultrafilters were examined with a combination of seven membrane types [2]. Membranes varied from nylon base to cellulosic to non-cellulesic polymerics. Tubular size varied from hollow fibers to 6mm inside diameter nylon; to 254 mm diameter series; and on four parallel 125 mm inside diameter tube modules.

Results: The one 254 mm diameter non-cellulosic membrane module chosen from the 4 manufactures will be specified for a 144,400 gpd (546.6 M^3/d) tubular ultrafilter to pretreat raw sewage prior to the spiral wound R/O. During 1981-82 the following re-use system will be used. Raw sewage at 100 gpm (144,400 gpd - 546.6 M^3/d) will be screened thru a 90 mesh vibrating screen to eliminate fiberous and other larger than suspended solids matter. From limited storage tanks the screened sewage will pass thru ultrafilters prior to demineralization by spiral wound R/O units. After the R/o units the product water will be treated with ozone and/or free radical hydroxyl ions: and ultraviolet light then to granular activated carbon followed by disinfection. 10,000 gpd (37.9 M^3/d) of treated water will be used in the sod grass production farm. The remaining product will be discharged back to the sewer system until other uses are legal. An alternate companion experiment will run: raw sewage screened thru 90 mesh screen then 30,000 gpd (113.7 M^3/d) to an aquaspheric water hyacinths unit (3 day retention). The aquaspheric unit is designed to produce a typical hyacinth biproduct effluent. The quality of product will contain all of the humic, polycarbonaceous matter of an aquatic treatment system. For example, color, tannins, humic and fulvic acids with traces of cholorohypyl. The product with the above will be treated by ultrafilters followed by reverse osmosis, ozone, and activated carbon. This later experiment will define the problems associated with membrane treatment of aquaspheric treated product waters (hyacinths and aquatic plants).

These last described experiments, a 30,000 gpd (113.7 M^3/d) are designed to give field tested experience of water reuse using the following tools: raw sewage to ultrafilters, aquaspheric waters, reverse osmosis, free radical oxidation, and/or ozone oxidation and carbon adsorption. These tests shall prepare the City of San Diego to go to the next 1.0 MGD aquatreatment hyacinth plant to be designed and built in 1982-83.

A request for proposals [5] will bring submittals on the design, building and operations of an aquatreatment based 1.0 MGD plant in August 1981.

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ON-SITE WASTEWATER RECLAMATION AND REUSE SYSTEMS IN COMMERCIAL BUILDINGS AND APARTMENT COMPLEXES

Takashi Asano
Office of Water Recycling
California State Water Resources Control Board
P.O. Box 100
Sacramento, California 95801

Yasuyuki Nagasawa
Japan Housing Corporation
6-14, Kudan-Kita 1 chome
Chiyoda-Ku, Tokyo, Japan

Noboru Hayakawa and Takashi Tamaru
Nishihara Environmental Sanitation Research Corp., Ltd.
6-18, 3-chome, Shibaura
Minato-Ku, Tokyo, Japan

Despite the apparent abundance of annual average rainfall of 1,800 mm, Japan's freshwater availability on a per capita basis is approximately one-fifth of that of the United States and Sweden. There are many factors associated with the current and predicted water shortages in Japan. Seasonal and geographical variations in rainfall during the monsoon and typhoon seasons in the Pacific and Japan Sea Coasts have presented difficult water resources development and management problems both in flood and drought years.

In 1970, the domestic and industrial water demands were approximately 34 percent of the total water demand, and water use in these categories is expected to reach 48 percent in 1985. These figures reflect the overall increasing demand for household water uses which include: flush toilets, washing machines, and hot-tub baths (rather than the traditional public bath houses), and for industrial water demands as reflected by the tremendous increase in the Gross National Product (GNP) in recent years. As a result, there have been serious water supply shortages in the major metropolitan centers of Japan: Tokyo in 1964 for 84 days; Nagasaki and Kita-Kushu in 1967 for 72 and 130 days, respectively; Matsue, Takamatsu, and Ohotake in 1973 for 135, 58, and 49 days; and Fukuoka in 1978-79 for staggering 287 days. Furtermore, it is estimated that the national water shortage will reach $1.5 \times 10^9 m^3$ in 1985 and even the new local water resources developments will be unable to meet anticipated demands by the year 1990 in the following three major population centers of Japan: Tokyo, Osaka, and Kita-Kushu.

To alleviate this potentially catastrophic condition, there have been several water conservation measures implemented in large metropolitan centers which included on-site wastewater reclamation and reuse. This paper will focus on the unique features of the on-site wastewater reclamation and reuse systems in commercial buildings and apartment complexes as practiced in Japan. The primary impetus for the on-site water reclamation and reuse systems arises when large volume water-demanding facilities such as large commercial buildings and apartment complexes are being planned, potential building ban due to the limited capacities of water supply, sewer, and wastewater treatment facilities may be lifted on the basis of adopting on-site water reclamation and recycling systems. The secondary impetus for including such systems come from the realization that the vulnerability of the water supply systems under catastrophic incidences such as earthquakes may be reduced and thereby the minimum environmental sanitation may be sustained in the metropolitan areas.

Since 1970, facilities planning for municipal wastewater reclamation and reuse and industrial water recycling has been initiated by local and national government agencies. In Metropolitan Tokyo, for example, installations of dual water supply systems and on-site wastewater reclamation and reuse facilities in special planning districts have been promoted for toilet flushing water and for air-conditioning makeup water in large buildings and apartment complexes. Also, in Fukuoka City where water supply was restricted for over 19 hours per day in 1978, due to the severe drought, water conservation programs must be submitted to the City if the water supply pipes to the buildings are greater than 50mm in diameter or if the floor space of the building is more than 5,000 m^2.

Because of these governmental directives, there has been a steady increase in the number of wastewater reclamation and reuse facilities installed or being planned. There were over 100 projects as of 1980 in the water-short areas of Japan. To promote these projects, a financial assistance program for the installation of water reuse systems was established in 1979 by the National Government to grant a low interest rate loan through the Japan Development Bank upon the recommendation of the prefectural governors.

CURRENT STATUS OF ON-SITE WASTEWATER RECLAMATION AND REUSE IN JAPAN

Among several water supply alternatives, the on-site wastewater reclamation and reuse systems have been considered the most attractive and implementable due mainly to the following reasons:

1. They may be able to provide a solution to the water supply and demand inbalances *in situ*, or on a regional basis where the concentration of population and industries has created water shortages.

2. Implementation of on-site wastewater reclamation and reuse systems results in reduction of water intakes as well as reduction in pollutant loads in the receiving water.

3. Although on-site wastewater reclamation and reuse systems are costly at present, they are nonetheless financially feasible on a long-term basis with the aid of government subsidies.

4. In many instances advanced waste treatment is required for effluent discharges, and the technology associated with advanced waste treatment systems has been well established. In these instances, the wastewater reclamation and reuse systems may be easily adopted.

In addition to the rationales given above, on-site wastewater reclamation and reuse systems become a necessity when the increased volume of wastewater cannot be adequately handled by the existing sewers due to the capacity limitations. Furthermore, the mass emission rate of pollutants must be reduced for the protection of the fishery resources and the other beneficial uses in receiving waters.

Classification of On-Site Wastewater Reclamation and Reuse Systems

Wastewater reclamation and reuse systems may be classified in accordance with the size of the facility and the area served. An individual on-site reuse and recycling system consists of reclamation of wastewater and reuse within buildings such as schools and commercial establishments. Since the recycling system is normally confined to one building, wastewater reclamation facilities and distribution systems may be smaller and may be designed on an individual basis; however, the required space must be provided for the treatment facilities within the building proper.

A regional reuse and recycling system is implemented on a collective basis such as in apartment complexes or in commercial and financial districts where wastewaters from these buildings are collectively reclaimed and re-supplied to the same buildings in the district. Since these buildings are located in relatively small confines, it is easier to define water use characteristics and wastewater quality.

The wastewater reclamation and reuse systems may be further expanded to the terminal wastewater treatment plant where municipal wastewater is treated and reclaimed by advanced waste treatment processes. There are several advantages for a large-scale wastewater reclamation and reuse operation that the effect of water conservation could be considerable, and the unit cost of reclaimed water would be less costly. However, due to the distances involved in the necessary distribution lines, the costs could be prohibitively high both in material and construction costs, particularly in well established and congested downtown areas. Thus, the large-scale wastewater reclamation and reuse systems may be implemented only in newly developed areas such as in a "new town" or in reclaimed lands near oceans.

Tables 1 and 2 summarize the current status of major reclaimed water use and recycling in various applications, and the volume of reclaimed water use. Almost all reclaimed water use is for toilet flushing water, with only a limited amount used for cooling water, ornamental lake, cleansing water, and fire hydrants. Because of the relative ease in implementation, 47 installations or 90.4 percent are individual on-site reuse and recycling systems, and reclaimed water use of 101 - 500m^3/day is the most common.

Water Quality Requirements and Treatment

There have been several water quality standards established for water supplies such as for drinking water, public bathing, and swimming pools, but there have not been any uniform standards for the on-site wastewater reclamation and reuse systems. However, based on experiences gained through the pilot and demonstration facilities, there are some common bases to be considered in formulating any such standards and criteria. These criteria should include: (1) public health, (2) aesthetics and public acceptance, (3) maintenance (such as corrosion prevention) of piping and distribution systems, and (4) reliable operation of treatment facilities.

Among the reuse and recycling systems reported in Table 2, influent biochemical oxygen demand (BOD_5) and suspended solids (SS) are reported to be in a range of 70-750 mg/l, and 60-600 mg/l, respectively. After treatment, reclaimed water quality is in a range of BOD_5 3-30 mg/l, chemical oxygen demand (COD) 5-40 mg/l, SS trace to 30 mg/l, normal-hexane extract 0-8 mg/l, and ABS 0-2 mg/l, respectively.

Several treatment processes and operations are used in the wastewater reclamation and reuse systems in accordance with wastewater characteristics and dependent on the intended reuse applications. Typically, wastewater will undergo treatment trains of screening, on-line flow equalization, biological oxidation, media filtration, and disinfection. Chemical coagulation-flocculation steps may be added before the filtration. In a case of physical-chemical treatment sequences, chemical coagulation-flocculation, membrane process, and activated carbon treatment are used. Figure 1 shows standard flow sheets for the treatment trains used in the on-site wastewater reuse systems. Table 3 shows a summary of treatment trains used in the on-site wastewater reclamation and reuse systems in commercial buildings and apartment complexes.

It is noted in Figure 1 that the activated sludge process and the direct media filtration of the effluent are the most common treatment trains for the on-site wastewater reclamation and reuse systems. Out of 17 installations using treatment train No. 1 (Table 3), four use ozonation and two use activated carbon treatment as an additional treatment step. Next to the treatment train No. 1, 11 installations use treatment train No. 3 consisting of two step biological processes: normally activated sludge process plus attached growth biological systems such as submerged media biological contactor or rotating biological contactor. The effluent is filtered before being stored in a reclaimed water storage tank. Of 11 installations reported in Table 3 for the treatment train No. 3, three installations use ozonation and two use ion exchange as additional treatment steps.

CASE STUDIES

The following two case studies describe a detailed analysis of the on-site wastewater reclamation and reuse systems practiced in an apartment complex and commercial buildings. Design factors, water quality criteria, distribution systems, and economic analyses are discussed in detail, and practical experiences gained from the projects are summarized.

1. On-Site Wastewater Reclamation and Reuse in an Apartment Complex

The S apartment complex is located approximately 30 Km east of the Tokyo Metropolitan area, and consists of 2,250 apartments. An on-site wastewater reclamation and reuse system was constructed in 1978 to supply reclaimed water to 888 rental units, totaling 3,220 residents, in eight to eleven story buildings in one section of the apartment complex. The intended uses of reclaimed water were for toilet flushing, cleansing water for garbage collection areas, and an ornamental pond and stream.

Based on the water use survey results shown in Table 4, reclaimed water uses for toilet flushing and cleansing purposes were estimated to be 50 ℓ per capita per day, thus a total flow rate of $160m^3$/day was used for facilities design.

The water quality criteria for reclaimed water are shown in Table 5. A summary of wastewater treatment facilities at the S apartment complex is shown in Table 6. A portion of the tertiary treated effluent after chemical coagulation and filtration serves as an influent to the on-site wastewater reclamation and reuse system. Figure 2 represents a schematic diagram of the wastewater reclamation and reuse system.

Treatment Facilities

As shown in Figures 2-a and 2-b, wastewater from the apartment complex (average effluent BOD 200 mg/ℓ and SS 250 mg/ℓ) undergoes the following treatment trains: screening, aerated grit chamber, comminutor, extended aeration activated sludge process, sedimentation, alum coagulation, sedimentation, dual media filtration. Effluent water qualities from these treatment processes are approximately BOD 10 mg/ℓ and SS 10 mg/ℓ, respectively, which are required to meet discharge standards. Approximately 75-80 percent of the effluent are discharged at this stage after chlorination (Figure 2-a).

The remaining 20-25 percent of the effluent are subjected to the on-site wastewater reclamation and reuse systems. Intake water is withdrawn from the splitter box located between the dual media filter and the chlorination tank. The main element of wastewater reclamation facilities as shown in Figure 2-b consists of an ozonation facility for color and odor removal, and disinfection. There have been special safety features incorporated in the ozonation facility, and the following safety features are derived from pilot-scale experiments: 1) automatic control of ozone generation to prevent excess ozone generation, 2) a stand-by ozone generator for shut-down and maintenance, 3) deozonation facility (adsorption tower) to prevent secondary pollution, and 4) special ventilation facility for the ozone generator room. With respect to reclaimed water quality assurance, continuous automatic monitoring of TOC and turbidity is conducted in the following schedule: 1) if TOC and turbidity values exceed 15 mg/ℓ and 5 units, respectively, for 15 minutes, reclaimed water flow is automatically switched to additional treatment of activated carbon treatment with a sound of alarm, 2) if water quality values after activated carbon treatment still show excess, the on-site reclamation and reuse system shuts down. Then, potable water will be introduced to the finished water reservoir in lieu of the reclaimed water.

Reclaimed Water Distribution Systems

The reclaimed water distribution systems for the S apartment complex involve distribution pumps, pressure tanks, outside and inside pipings, toilet equipment, and recirculation systems for ornamental lake and stream. Figure 3 shows the schematic diagram of these facilities. To distinguish reclaimed water lines from the potable water lines, epoxy coated steel pipes were used and pipes were clearly marked with a marking tape.

Since the flat-rate water pricing is used, flow meters are installed only to a group of apartment units for future evaluation. A yellowish-color toilet was used to mask potential coloring of the toilet facilities by the reclaimed water.

Reclaimed Water Quality

An intensive monitoring to characterize reclaimed water qualities at the point of reuse was conducted from February 1978 to October 1978. The results are reported in the following statistical parameters: arithmetic mean, 97.5% confidence limit, and 90% confidence limit. The results are reported in above order for the following water quality parameters: color 0.9, <6, <2; turbidity 0.3, <3, <1, total dissolved solids 445,600,540 mg/ℓ; SS 1.3, 4.0, 2.7 mg/ℓ; COD 3.5, 6.7, 5.4 mg/ℓ; BOD_5 2, 4, 3 mg/ℓ; PO_4^{3-} 0.5, 1.8, 1.4 mg/ℓ; TOC 4.1, 9.2, 7.2 mg/ℓ, respectively.

Capital and O & M Costs

Capital cost items for the on-site wastewater reclamation and reuse system consist of wastewater reclamation facilities (ozonation, activated carbon treatment, and monitoring), indoor and outdoor pipings, reclaimed water reservoir tank, and distribution and pumping systems. Table 7 shows cost breakdown of these facilities.

Based on the construction costs shown in Table 7, per apartment unit construction costs are approximately $873 each, and, based on the prevailing interest rate and amortization, a monthly payment per an apartment would amount to $6. At the S apartment complex, $2.20 are collected monthly per apartment to cover operation and maintenance costs (O & M) for the on-site wastewater reclamation and reuse system. Since reclaimed water use per apartment is estimated to be 6 m^3/month (average 4 persons per dwelling unit), the reclaimed water costs including capital and O & M would become $1.36 per cubic meter.

At the S apartment complex, however, only the O & M costs in the amount of $2.20 are collected from the residents. Thus, the use of reclaimed water would amount to 38¢ per cubic meter, and the cost of the reclaimed water compares favorably with the prevailing cost of a tap water at 62¢ per cubic meter.

Public Acceptance

Since the ultimate success of the on-site wastewater reclamation and reuse system is dependent on actual public acceptance of the reclaimed water, a side-by-side public opinion survey of the reclaimed water users and non-users of the S apartment complex was conducted in August - October 1978. The sampling size and composition of the survey are reported in Table 8.

Among the reclaimed water users and non-users, 61.3 percent answered that they are concerned about water conservation, and only 1.4 percent considered that water conservation is not necessary. Understandably, more women (71.1%) are aware of the necessity of water conservation. With respect to actual use of the reclaimed water for toilet flushing, 84.5 percent considered that they have not noticed any difference from tap water, and only 3.1 percent noticed some differences. With respect to esthetic qualities of the reclaimed water such as odor, foam, and color, overwhelming majorities felt that the reclaimed water made no differences (odor: 81.1% male, 77.3% female; foam: 85.8% male, 77.7% female; color: 81.3% male, 74.2% female).

With general questions regarding water shortages and water pollution, 52.6 percent considered wastewater reclamation and reuse should be promoted actively and 36.5 percent considered that wastewater reuse is unavoidable. Only 7.2 percent responded negatively to the wastewater reuse, and suggested alternative water supply. In general, the reclaimed water users showed better understanding of the necessity and use of reclaimed water in the community.

2. Regional Wastewater Reuse and Recycling System for the Commercial Buildings

The area from the Tokyo Train Station to the Imperial Palace includes major government and commercial districts where many headquarters of major corporations are located. Since September 1976, a district heating and air-conditioning corporation has been operating to provide necessary building services to the selected buildings in this area for the heating, air-conditioning, and reclaimed water. The objectives of the collective utility corporation in the district are: (1) efficient energy utilization, (2) reduction in utility space requirements in an individual building, (3) hazard prevention and esthetics, and (4) alleviation of operator and maintenance manpower shortages.

The district wastewater reclamation and reuse system was planned as a part of the utility services originating at the O building. The sources of water for the reuse system are grey waters from three surrounding buildings and blow-down water of a cooling tower at the O building. The use of reclaimed water is for toilet-flushing. Since the on-site wastewater reclamation and reuse system is located in the basement of the O building, special safety precausions were incorporated. Table 9 shows a description of the commercial buildings where reclaimed water is supplied from the O building service station.

Figure 4 shows a schematic diagram of the water supply and reclaimed water systems for the three buildings.

On-Site Wastewater Reclamation and Reuse System for the Commercial Buildings

Table 10 shows grey water influents to the on-site wastewater reclamation systme and the volume of planned reclaimed water use.

The wastewater reclamation facilities consist of grey water treatment by the activated sludge process and the treatment of cooling water blow-down by chemical treatment. The two streams are then combined to undergo a media filtration. Figure 5 shows this regional wastewater reuse and recycling system for the commercial buildings. Table 11 shows design specifications for the treatment systems.

Operational Characteristics

As shown in Table 10, influent flows from three buildings consisted of grey waters and a cooling water blow-down. Daily grey water flow was in a range of 178 to 270 m^3, and the average was 212 m^3/day which was approximately 72 percent of the design flow. The summer month flows were approximately 1.6 times higher than the winter month flows. The reclaimed water use was, on an average, 385 m^3/day for working days, and 23 m^3/day for holidays and weekends.

Table 12 shows average water quality characteristics of the influent grey water and the reclaimed water after treatment shown in Figure 5.

Capital and O & M Costs

Since the on-site wastewater reclamation and reuse systems are installed underground in the second and third floors, the construction costs are considered to be approximately 30 percent higher than the equivalent facilities above ground. Table 13 summarizes capital and O & M costs for the production of 476 m^3/day reclaimed water. Annaul reclaimed water use was based on 300 working days, and calculated to be 142.8 x 10^3 m^3/year. Based on the total O & M cost items, direct cost attributable to the production is 55¢/m^3 which includes operator, electricity, and miscellaneous cost items.

The current water supply costs, on the other hand, are approximately \$1.20/m^3 for large users, and the sewer use charge is about 69¢/m^3 in Metropolitan Tokyo, totaling \$1.89/m^3. Thus, the reclaimed water is still considered to be cheaper than the existing municipal water supply.

CURRENT PROBLEMS AND FUTURE PROSPECTS

Institutional

Through the governmental administrative directives, there has been a steady increase in the number of on-site wastewater reclamation and reuse facilities in Japan, totaling over 100 projects as of February 1980. Laws and regulations governing the use of reclaimed water are complex, and confusing at this time. There have been the established acts governing the potable water supply, sewerage, and industrial water, respectively enforced by the Ministeries of Health, Construction, and Industry and Trade. By introducing reclaimed water into this complex picture, some procedures must be established to incorporate reclaimed water into the traditional water supply - wastewater receiving functions of a municipality.

Several potential problems confronting the extended use of reclaimed water for municipalities are identified below:

1. Establishment of uniform standards of safety with respect to reclaimed water quality, structures and facilities, and

operation and maintenance.

2. Rational methods of enforcing the use of lower quality water (reclaimed water by origin) to a selected water reclamation district.

3. Pricing policy and methods of cost allocation, e.g., federal and local governments, and users.

4. Accommodation of reclaimed water in the existing water supply and sewerage regulations, and needs for new legislation.

Economics

Uniform accounting methods for pricing reclaimed water have not been established. The cost of reclaimed water may be calculated on the basis of direct costs attributable to O & M; on the other hand, amortization of the capital cost items may be included in the pricing policy. In addition, general cost estimates for required land, construction, and O & M are difficult to establish and general cost trends regarding the treatment facilities, pipings, and distribution facilities have not been established.

Additional treatment steps which may be required for the production of reclaimed water will depend on the effluent discharge regulations of the area. Thus, whether to consider the on-site wastewater reclamation and reuse systems as wastewater treatment systems or unique water treatment facilities will affect cost of reclaimed water. It is a common practice to compare the price of reclaimed water with that of potable water supply, and it is often the case as a result that reclaimed water is found to be more costly. The reasons are often due to the stricter water quality requirements for reclaimed water than for wastewater discharge, O & M costs, necessities of additional treatment trains and dual water supply systems. When an amortization of the capital cost items are included in the pricing of reclaimed water, it is reported that the reclaimed water is 1.5 to 2 times more costly than the existing potable water supply at present for apartment complexes, and for an individual on-site wastewater reclamation and reuse system.

However, it is anticipated that the next large increment of freshwater supply will be much higher in cost than existing supplies due mainly to the remoteness of new water sources, escalating energy and delivery costs, and environmental considerations. With the introduction of a large scale wastewater reclamation and reuse along with stricter discharge regulations, it is probable that the reclaimed water will become more and more competitive in price in the future. In addition to the existing low-interest loan from the Japan Development Brank for the wastewater reclamation and reuse facilities, some forms of financial assistance may be introduced to the on-site wastewater reclamation and reuse systems similar to the existing subsidies for water supply and wastewater treatment facilities.

Public Health and Engineering

As discussed earlier, the current practice of reclaimed water use is largely limited to toilet flushing, and ornamental and landscape irrigation where human contacts are kep minimum. In the expanded use of reclaimed water, the major concerns are to minimize health risks associated with viruses and toxic substances. Because of these concerns, the on-site wastewater reclamation and reuse systems normally consist of biological secondary treatment, chemical coagulation and flocculation, media filtration, and possibly carbon adsorption. A combination of ozonation and chlorine disinfection is often used for the inactivation of viral agents. No virus detection is reported in Japan so far in a reclaimed water after media filtration followed by chlorination and ozonation in these systems.

Major water quality concerns related to the use of reclaimed water are: (1) turbidity, (2) odor, (3) foaming, (4) coloring to toilet facilities, (5) slime and scaling, and (6) corrosion control. Uniform standards for these water quality concerns are expected to be established in the future when adequate experiences are gained from the existing and future wastewater reclamation and reuse projects.

From the engineering standpoints, the on-site wastewater reclamation and reuse systems require additional internal piping, storage tank, raised distribution tank, pumping, and other treatment facilities which require special considerations for space requirements, structural safety, and space and construction expenses. Special attention must be paid to construction methods and compact installations of the equipment. Due to the dual piping systems required for buildings, positive cross-connection prevention measures must be exercised and uniform identification of the reclaimed water piping must be developed and enforced.

SUMMARY AND CONCLUSIONS

As the demand for water increases, wastewater reclamation and reuse becomes an increasingly important source for meeting some of this demand. Because wastewater reclamation and the planned use of reclaimed water are so closely linked to the freshwater supply of a region, significant wastewater reuse projects are typically implemented in water-short areas, particularly in the metropolitan centers.

There are many factors associated with the current and predicted water shortages in Japan. These water shortages reflect the overall increasing demand for household water uses and for industrial water demands as reflected by the tremendous increase in Gross National Product in recent years. To alleviate this potentially catastrophic condition, there have been several water conservation measures implemented in large metropolitan centers which included on-site wastewater reclamation and reuse. The paper focused on the unique features of the on-site wastewater reclamation and reuse systems in commercial buildings and apartment complexes as practiced in Japan. For these applications, wastewater will typically undergo treatment trains of screening, on-line flow equalization, biological oxidation, media filtration, and disinfection. Chemical coagulation-flocculation and carbon absorption steps may be added to the typical treatment trains with ozone treatment. Two case studies were cited in detail including cost analyses.

Several potential problems confronting the extended use of reclaimed water for municipalities were identified. Those unresolved areas of reclaimed water use include rational methods of enforcing the use of lower quality water (reclaimed water by inference) on a selected water reclamation district and incorporating reclaimed water into the traditional water supply - wastewater receiving responsibilities of a municipality. Uniform accounting methods for pricing reclaimed water have not yet been established. The cost of reclaimed water may be calculated on the basis of the cost items attributable to O & M. On the other hand, the amortization of the capital cost items may be included in the reclaimed water pricing policy if these items are in addition to the effluent discharge requirements of the affected area.

It is anticipated, however, that the next large increment of freshwater supply will be much higher in cost than existing supplies due mainly to the remoteness of new water sources, escalating energy, construction, and delivery costs, and environmental considerations.

Thus, with implementation of the large scale wastewater reclamation and reuse systems along with enforcement of the stricter effluent discharge requirements, it is anticipated that the reclaimed water is becoming more and more competitive in price in the foreseeable future.

TABLE 1. Reclaimed Water Use and Recycling in Various Applications

Applications	Number of Installation	Percent	Toilet Flushing Water	Cooling Water	Ornamental Lake	Cleansing Water	Laboratory Water	Fire Hydrant
I. Individual On-Site Reuse and Recycling								
Office	29	55.8	29	5	3	3		1
Store	3	5.8	3	3	1			
School	6	11.6	6	1				1
Hospital	2	3.8	2					
Hotel	2	3.8	2					
Clubhouse	4	7.7	4		1			
Housing	1	1.9	1		1	1		
Sub-Total	47	90.4	47	9	6	4		2
II. Regional Reuse and Recycling								
Office	2	3.8	2	1				
Apartment	2	3.8	2		2	1		
Research Institute	1	2.0		1			1	
Sub-Total	5	9.6	4	2	2	1	1	
Total (I and II)	52	100.0	51	11	8	5	1	2

TABLE 2. Volume of Reclaimed Water in Various Applications

Applications	Number of Installations	Flowrate, m^3/day 0-10	11-50	51-100	101-500	501-1,000	1,001-5,000
I. Individual On-Site Reuse and Recycling							
Office	29	6	10	2	9	1	1
Store	3		1	1	1		
School	6	2	3		1		
Hospital	2			1			1
Hotel	2				2		
Clubhouse	4		1	1	2		
Housing	1		1				
Sub-Total	47	8	16	5	15	1	2
II. Regional Reuse and Recycling							
Office	2				2		
Apartment	2				2		
Research Institute	1			1			
Sub-Total	5			1	4		
Total (I and II)	52	8	16	6	19	1	2

TABLE 3. Summary of Treatment Trains Used in the On-Site Wastewater Reclamation and Reuse Systems
(For the treatment flow sheet, refer to Figure 1)

Applications	Standard Flow Sheet						
	No. 1	No. 2	No. 3	No. 4	No. 5 & 6	No. 7 & 8	Others
I. Individual On-Site Reuse and Recycling							
Office	12	4	4		6	1	2
Store	1		2				
School		1	3	1			1
Hospital	1		1				
Hotel				1		1	
Clubhouse	2	1					1
Housing							1
Sub-Total	16	6	10	2	6	2	5
II. Regional Reuse and Recycling							
Office	1		1				
Apartment		1		1			
Research Institute						1	
Sub-Total	1	1	1	1		1	
Total	17	7	11	3	6	3	5

TABLE 4. Average Daily Water Use in Various Applications (ℓ/day/cap.)

Bath-tub	Laundry	Bathroom	Kitchen	Toilet	Cleansing	Car-Washing
50	60	30	50	40*	10*	10

*Reclaimed water uses for toilet flushing and cleansing; 50ℓ/day/capita.

TABLE 5. Water Quality Criteria for Reclaimed Water Use in the Apartment Complex

Item	Unit	Criteria
Odor	-	non-existence
Color	Unit	<10
Turbidity	Unit	< 5
TDS	mg/ℓ	<1,000
SS	mg/ℓ	< 5
pH	Unit	5.8 - 8.6
COD	mg/ℓ	<20
BOD_5	mg/ℓ	<10
PO_4^{3-}	mg/ℓ	<1.0
ABS	mg/ℓ	<1.0
Coliform	count/mℓ	non-existence
General bacteria	count/mℓ	<100
Residual chlorine	mg/ℓ	>0.2
TOC	mg/ℓ	<15

TABLE 6. Summary of Wastewater Treatment Facilities at the S Apartment Complex

Population served	4,700
Wastewater generation	260ℓ/day/capita
Average wastewater flow rate	1,222 m^3/day
Secondary treatment	Extended Aeration
Tertiary treatment	Coagulation, flocculation, and filtration
Sludge treatment	Centrifugation
Treatment facility area	3,470 m^2
Structure	
Treatment tanks	Reinforced concrete, semi-basement roofed; 754 m^2
Control room	Reinforced concrete, two storied; 413 m^2

TABLE 7. Construction Costs* for the On-Site Wastewater Reclamation and Reuse System (160 m^3/day)

Facilities	Construction Costs	Percent	Items
Wastewater reclamation facilities	$403,624	52.0	Ozonation, monitoring, chlorination, activated carbon, and electrical
Indoor piping and facilities	83,534	10.8	Dual system piping
Outdoor piping and facilities	174,038	22.4	Dual system piping
Reclaimed water tank and facilities	114,162	14.8	Tank, distribution systems, electrical
TOTAL	$775,358	100.0	

*Conversion rate of ¥ 210 = $1 was used for the calculation.

TABLE 8. Public Acceptance Survey at the S Apartment Complex

Reclaimed Water Users			Non-Users		Total	
224 Apartment Units			301 Apartment Units		525 Apartment Units	
Male	204	426	275	555	479	981
Female	222		280		502	

*Fifteen years old or older residents participated in the survey.

TABLE 9. Description of the Buildings Where Reclaimed Water is Served

Building	Description	Toilet Facilities (No.)
T Office Building	14 stories above ground and 3 stories basement	Urinals: 61
Floor space	29,700 m^2	Toilets: 77
Population	1,400	
M Office Building	24 stories above ground and 3 stories basement	Urinals: 229
Floor space	125,800 m^2	Toilets: 394
Population	7,500	
O Service Building	4 stories basement	
Floor space	5,000 m^2	Urinals: 3
Population	10	Toilets: 3

TABLE 10. Volumes of Grey Water and Planned Reclaimed Water Use in the Buildings

Buildings	Influent Flow m^3/day		Reclaimed Water Flow m^3/day
T Office Building	Grey Water	65	95
M Office Building	Grey Water	185	375
O Office Building	Grey Water	44	6
	Cooling water blow-down	285	
TOTAL		579	476

TABLE 11. Design Specifications for the Regional Wastewater Re-use and Recycling System (Influent Flow: 579 m^3/day)

Equipment	Unit	Specifications
Ultrascreen	1 unit	110 m^3/hr. screen 0.5 mm
Flow Equalization Tank	200 m^3	16 hr. storage, 10 m^3 air/m^3 day
Aeration Tank	79 m^3	6.4 hr. aeration, 0.56 Kg BOD/m^3/day, 100 m^3 air/Kg BOD removed day
Sedimentation Tank	79 m^3	6.4 hr. sedimentation, 13 m^3/ m^2 day
Storage Tank	207 m^3	17 hr. storage
Chemical Mixing Tank	6.5 m^3	30 min. contact
Flocculation Tank	10 m^3	50 min. contact
Clarification Tank	55 m^3	4.7 hr. sedimentation
Filter Pump Well	16 m^3	
High Rate Filter	2 units	Downflow pressurized, 120 m^3/m^2/day
Chlorine Contact Tank	6 m^3	12 min. contact
Reclaimed Water Distribution Tank	360 m^3	15 hr. storage
Drainage Tank	45 m^3	To sewer liner discharge in non-use hours

TABLE 12. Average Water Quality Characteristics

Water Quality*	Influent Grey Water	Reclaimed Water
pH	6.9	7.6
SS	70	1
COD	49.5	5.2
BOD_5	66	2
Total - N	7	1
NH_3 - N	0.1	-
ABS	5.7	0.2
Total P	6.8	2.5

* mg/ℓ as stated except pH unit.

TABLE 13. Capital and O & M Costs* for the Production of 476 m^3/day Reclaimed Water (In Thousand Dollars)

Capital Cost Items:	In Thousand Dollars
Machinery and Construction	$523.8
Piping and Construction	166.7
Electrical	176.2
Structural	466.7
Miscellaneous	95.2
TOTAL	$1,428.6
O & M Cost Items:	
Rent for the Building	49.0
Maintenance	23.2
Property Tax	16.9
Amortization (Building: 30 Years Facilities: 7 Years)	141.4
Interest	100.0
Operator	25.2
Electricity (47,000 KwH/day)	29.3
Miscellaneous (water analysis)	24.0
TOTAL	$409.0

* ¥210 = $1.00 was used for cost conversion.

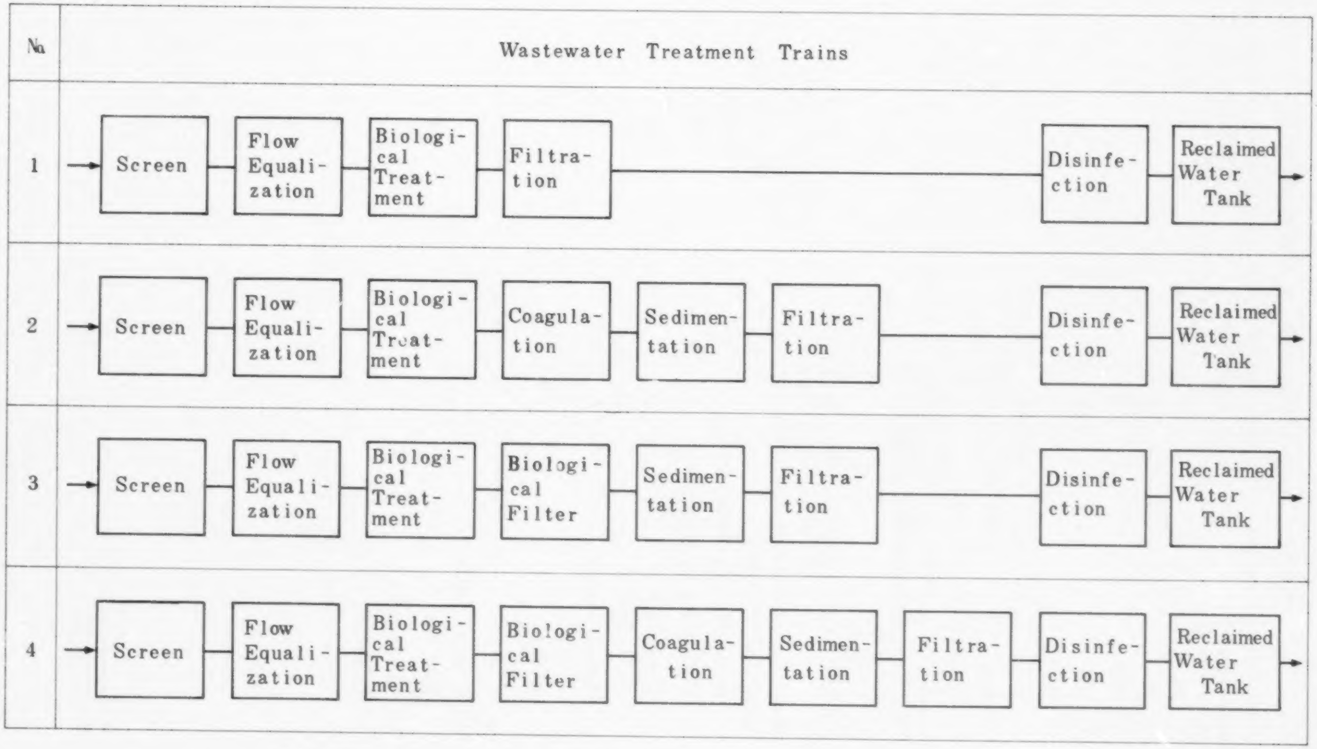
No.
Wastewater Treatment Trains
1
Screen
Flow Equalization
Biological Treatment
Filtration
Disinfection
Reclaimed Water Tank
2
Screen
Flow Equalization
Biological Treatment
Coagulation
Sedimentation
Filtration
Disinfection
Reclaimed Water Tank
3
Screen
Flow Equalization
Biological Treatment
Biological Filter
Sedimentation
Filtration
Disinfection
Reclaimed Water Tank
4
Screen
Flow Equalization
Biological Treatment
Biological Filter
Coagulation
Sedimentation
Filtration
Disinfection
Reclaimed Water Tank

Figure 1-a. Standard Flow Sheets for On-Site Wastewater Reuse Systems.

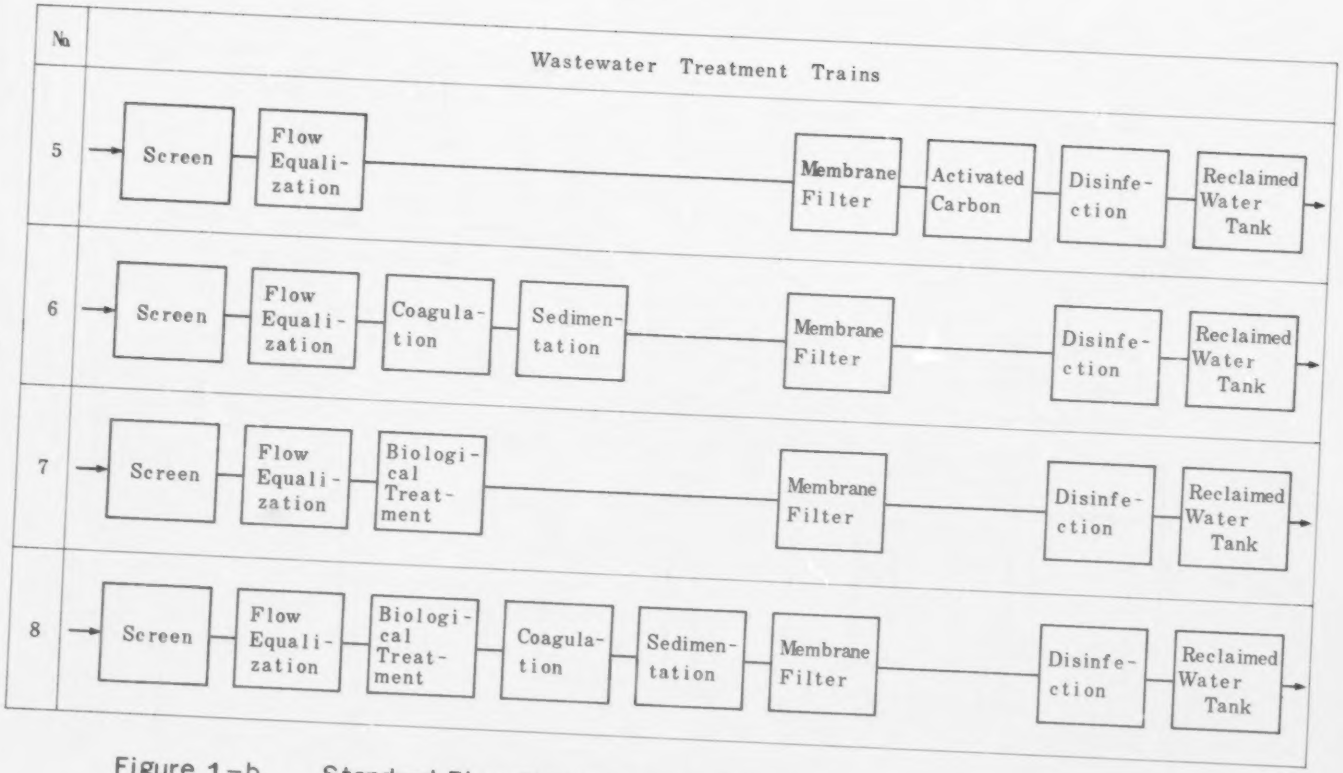
№
Wastewater Treatment Trains
5
Screen
Flow Equalization
Membrane Filter
Activated Carbon
Disinfection
Reclaimed Water Tank
6
Screen
Flow Equalization
Coagulation
Sedimentation
Membrane Filter
Disinfection
Reclaimed Water Tank
7
Screen
Flow Equalization
Biological Treatment
Membrane Filter
Disinfection
Reclaimed Water Tank
8
Screen
Flow Equalization
Biological Treatment
Coagulation
Sedimentation
Membrane Filter
Disinfection
Reclaimed Water Tank

Figure 1-b. Standard Flow Sheets for On-Site Wastewater Reuse Systems.

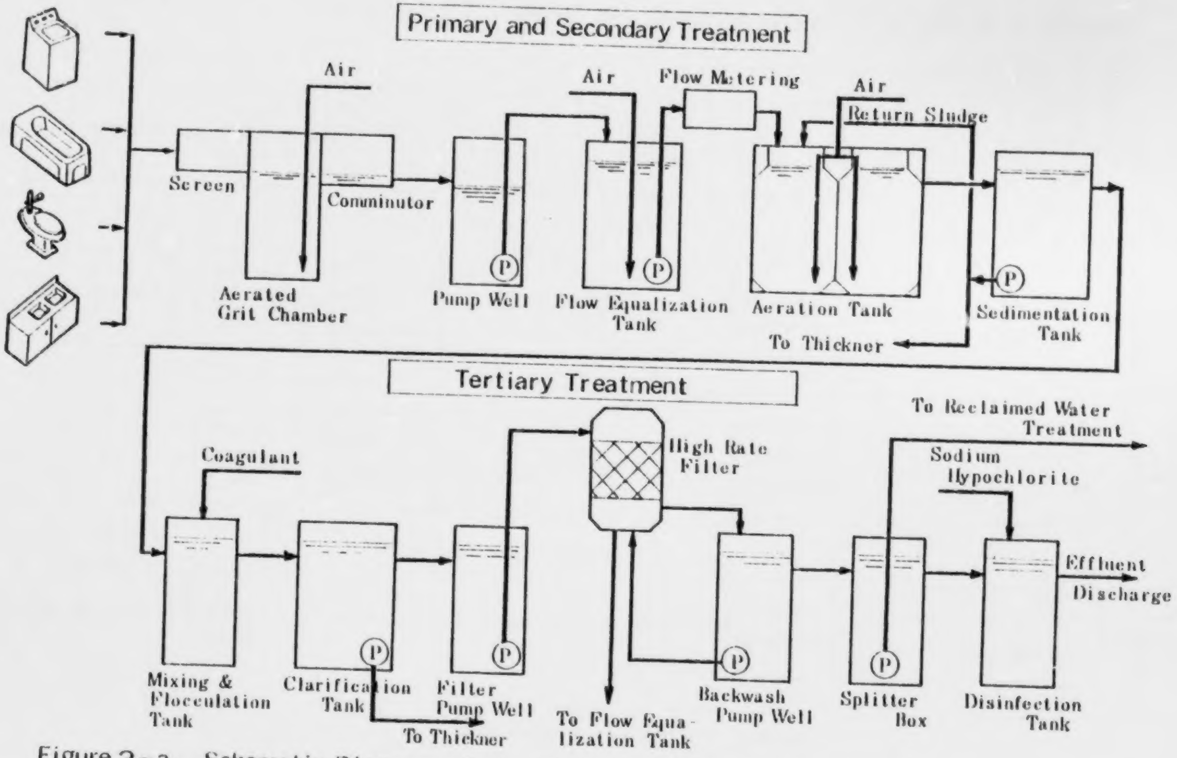
Primary and Secondary Treatment
Air
Screen
Comminutor
Aerated Grit Chamber
Pump Well
Air
Flow Metering
Flow Equalization Tank
Air
Return Sludge
Aeration Tank
To Thickner
Sedimentation Tank
P
Tertiary Treatment
Coagulant
Mixing & Flocculation Tank
Clarification Tank
To Thickner
Filter Pump Well
High Rate Filter
To Flow Equalization Tank
Backwash Pump Well
To Reclaimed Water Treatment
Sodium Hypochlorite
Splitter Box
Disinfection Tank
Effluent Discharge

Figure 2-a. Schematic Diagram of the On-Site Wastewater Treatment Systems and Reclamation Facilities at the S Apartment Complex.

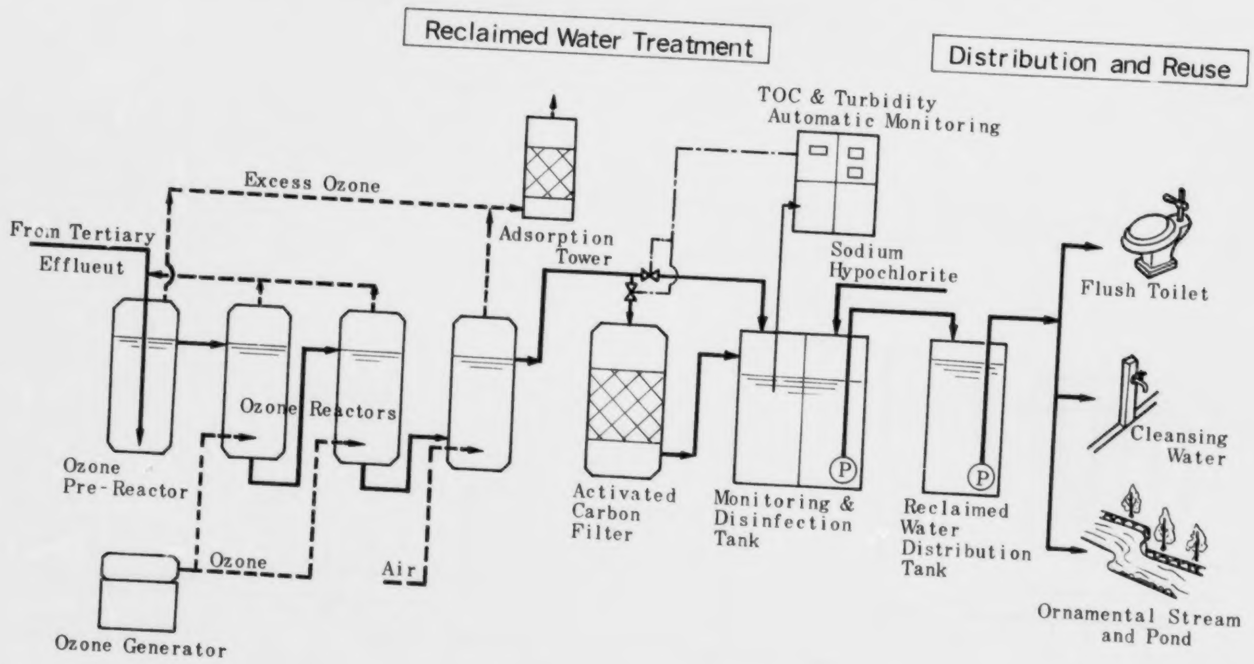
Reclaimed Water Treatment
Distribution and Reuse
From Tertiary
Efflueut
Excess Ozone
Adsorption
Tower
TOC & Turbidity
Automatic Monitoring
Sodium
Hypochlorite
Ozone
Pre-Reactor
Ozone Reactors
Ozone
Ozone Generator
Air
Activated
Carbon
Filter
Monitoring &
Disinfection
Tank
P
Reclaimed
Water
Distribution
Tank
P
Flush Toilet
Cleansing
Water
Ornamental Stream
and Pond

Figure 2-b. Schematic Diagram of the On-Site Wastewater Treatment Systems and Reclamation Facilities at the S Apartment Complex.

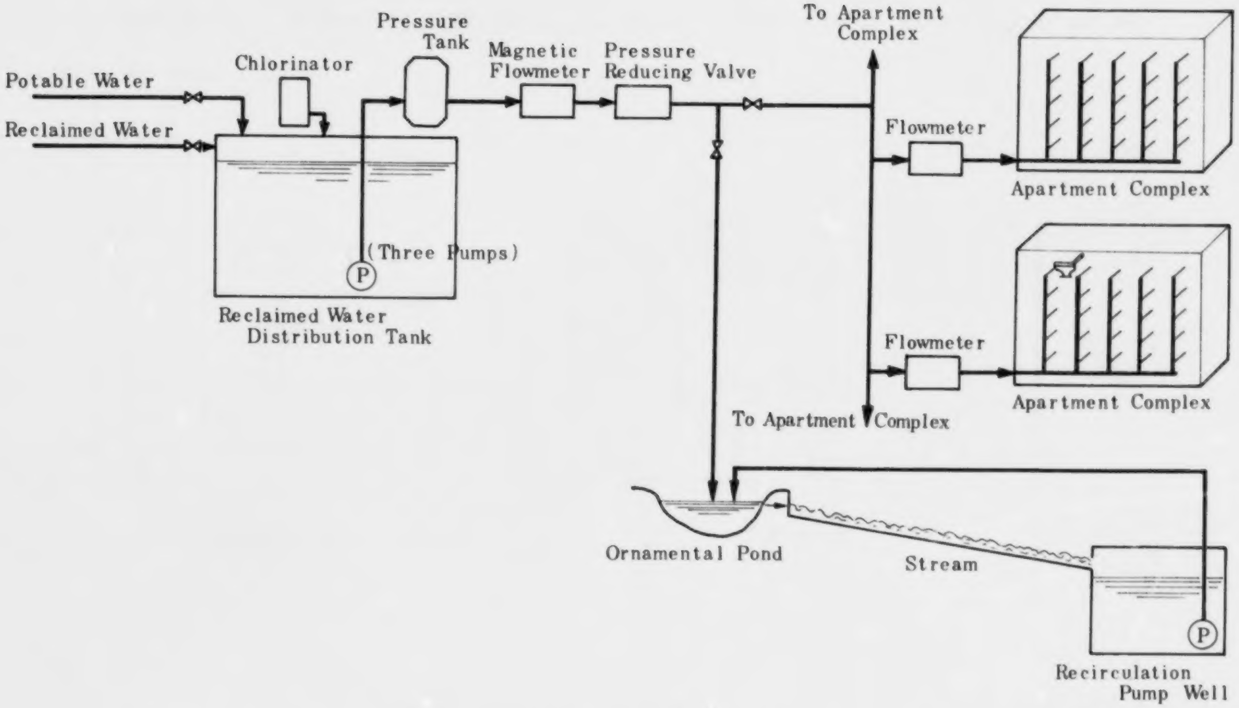
Potable Water
Reclaimed Water
Chlorinator
Pressure Tank
Magnetic Flowmeter
Pressure Reducing Valve
To Apartment Complex
Flowmeter
Apartment Complex
(Three Pumps)
P
Reclaimed Water Distribution Tank
Flowmeter
Apartment Complex
To Apartment Complex
Ornamental Pond
Stream
P
Recirculation Pump Well

Figure 3. Reclaimed Water Distribution Systems.

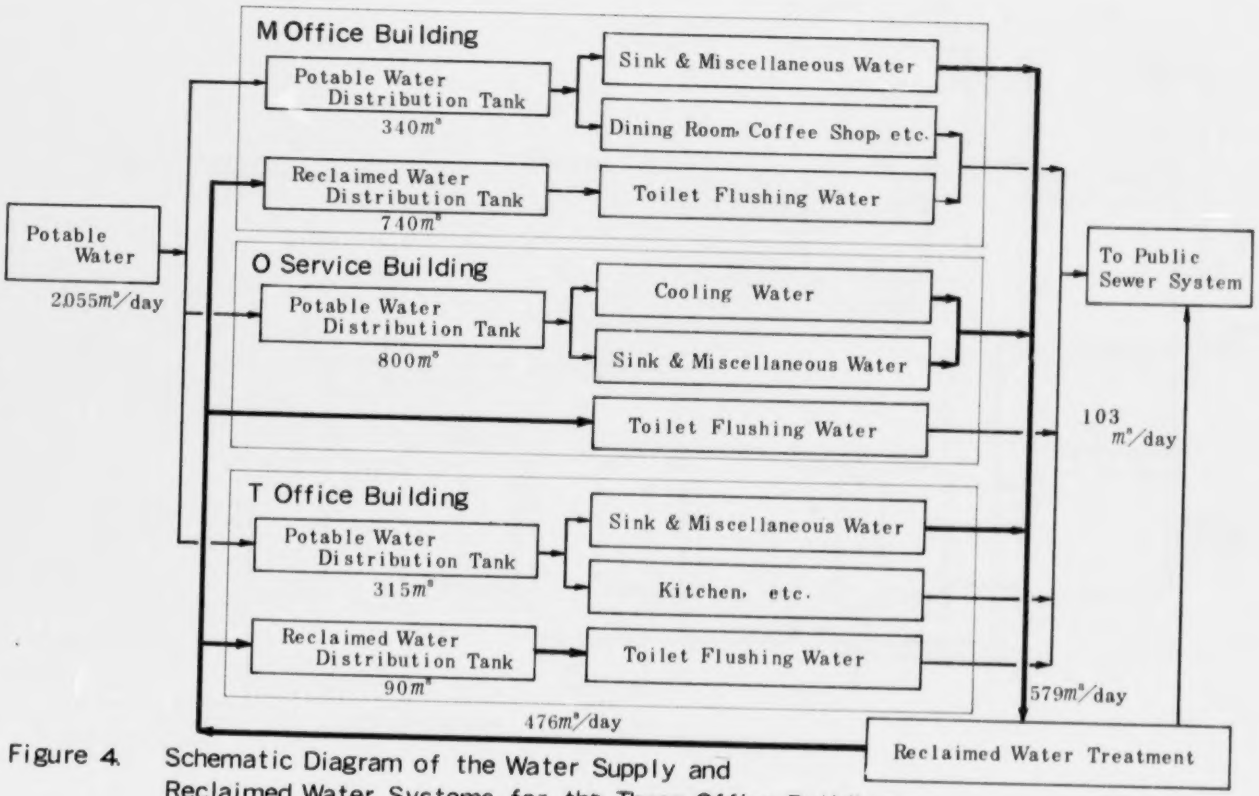
Potable Water
2,055m³/day
M Office Building
Potable Water Distribution Tank
340m³
Reclaimed Water Distribution Tank
740m³
Sink & Miscellaneous Water
Dining Room, Coffee Shop, etc.
Toilet Flushing Water
O Service Building
Potable Water Distribution Tank
800m³
Cooling Water
Sink & Miscellaneous Water
Toilet Flushing Water
T Office Building
Potable Water Distribution Tank
315m³
Reclaimed Water Distribution Tank
90m³
Sink & Miscellaneous Water
Kitchen, etc.
Toilet Flushing Water
To Public Sewer System
103 m³/day
579m³/day
476m³/day
Reclaimed Water Treatment

Figure 4. Schematic Diagram of the Water Supply and Reclaimed Water Systems for the Three Office Buildings.

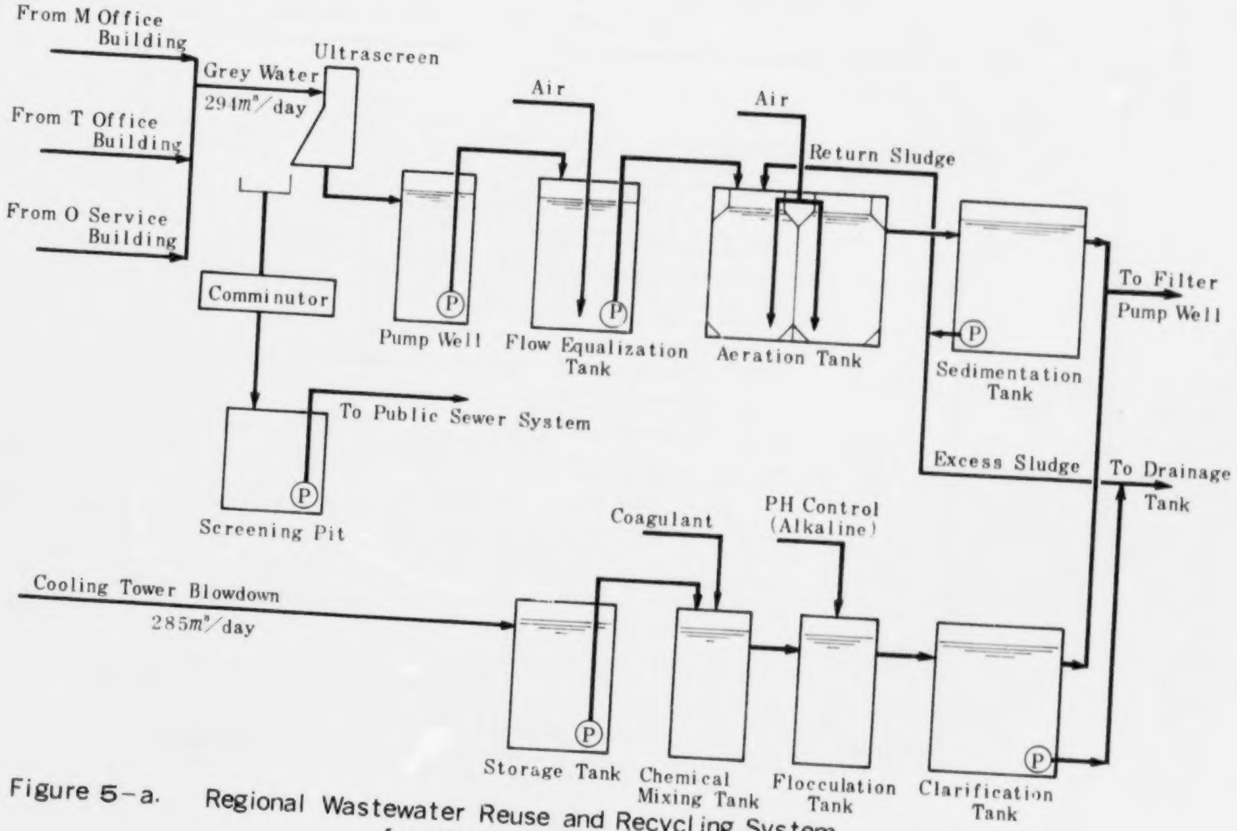
From M Office Building
From T Office Building
From O Service Building
Grey Water
294m³/day
Ultrascreen
Comminutor
Screening Pit
P
To Public Sewer System
Air
Pump Well
P
Flow Equalization Tank
P
Air
Return Sludge
Aeration Tank
Sedimentation Tank
P
To Filter Pump Well
Excess Sludge
To Drainage Tank
Cooling Tower Blowdown
285m³/day
Coagulant
PH Control (Alkaline)
Storage Tank
P
Chemical Mixing Tank
Flocculation Tank
Clarification Tank
P

Figure 5-a. Regional Wastewater Reuse and Recycling System for the Commercial Buildings.

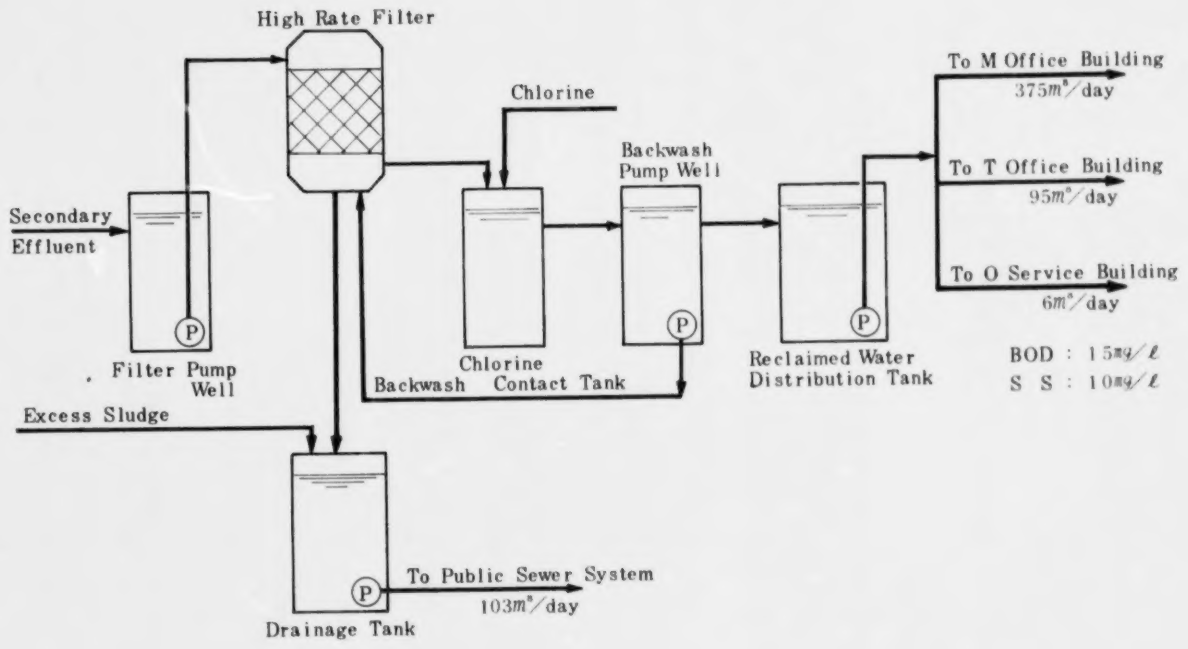
High Rate Filter
Secondary
Effluent
Filter Pump
Well
Excess Sludge
Chlorine
Chlorine
Backwash Contact Tank
Backwash
Pump Well
Reclaimed Water
Distribution Tank
To M Office Building
375m³/day
To T Office Building
95m³/day
To O Service Building
6m³/day
BOD : 15mg/ℓ
S S : 10mg/ℓ
P
Drainage Tank
To Public Sewer System
103m³/day

Figure 5-b. Regional Wastewater Reuse and Recycling System for the Commercial Buildings (Reclamation Facilities).

PB82-223256

SEQUENCING BATCH REACTOR (SBR) TREATMENT PLANT WITH ZERO DISCHARGE

J. William Bloemer, P.E.
Eaton Corporation
Manufacturing Services Center
Willoughby Hills, Ohio

R. Paul Farrell, P.E.
Robbins & Myers, Inc.
Springfield, Ohio
Formerly with Environment/One Corporation
Schenectady, New York

INTRODUCTION

The Eaton Corporate Manufacturing Services Center is an advanced manufacturing process development activity. A resident population of about 125 persons, plus groups of visiting "students" who attend manufacturing engineering seminars, make up the users of the facility. Assuming 250 working days per year, and a typical visiting population of 50 persons for 2 days per week, the person equivalent on a year-around average basis would be:

$$\frac{(125 \times 250) + (50 \times 100)}{250} = 145 \text{ Persons}$$

No industrial process wastes of consequence are generated, but a cafeteria serves excellent meals and is very popular. Food preparation is on site, and includes mechanical dishwashing and two commercial food waste disposers.

The wastewater load can thus be described as sanitary wastes from an average population of 145 persons, originating in the rest rooms and cafeteria kitchen of a single shift operation.

Treatment of this sanitary waste would normally be a routine matter, but in this instance there was no acceptable receiving stream within a reasonable distance. A Zero discharge plant, therefore, seemed the best way to comply with Ohio EPA requirements.

Eaton's corporate environmental engineering staff recognized this problem as an opportunity to gain first hand operating experience with some newer pollution control technology which could prove useful in the future at other corporate locations. They also determined to make this wastewater treatment facility a showplace indicative of the corporation's dedication to protecting the environment.

BACKGROUND

Sequencing batch reactors (SBR's) are not well known and have been used in a very limited number of applications to date.

In recent years a significant amount of research on SBR treatment has been done by Irvine at Notre Dame and others. (1,2,3,4,5,6,7,8,9). As Irvine noted, the original biological waste treatment process as discussed in the literature by Ardern and Lockett over sixty five years ago was a fill and draw (batch) process. (10,11,12). Biological treatment developed, however, along the lines of continuous flow systems (CFS) and the vast preponderance of operating plants in this country have been flow-through rather than batch systems.

Cashion et al[13] recently summarized one of the most obvious original shortcomings of the (CFS) system when they noted that in a conventional (CFS) activiated sludge system, regardless of efforts to control food to microorganism ratio (F:M), the single biggest factor affecting effluent BOD_5 is suspended solids passing over the wiers of secondary clarifiers. In their work covering batch (SBR) systems Farrell and Setser pointed out positive solids control as the single most significant improvement over conventional systems as claimed in their patented process. (14,15).

DESCRIPTION OF WASTEWATER TREATMENT PLANT

A sequencing batch reactor (SBR) was chosen as the principal element in the treatment process.

Plant operation is automatically controlled by sequencing and interval timers, and in response to control signals from various sensors. The control panel is pictured in Figure 1.

The batch process provides unusually consistent treatment over wide swings in either hydraulic or organic loading rates. The plant is very nearly closed down on weekends so operation consists of five day periods of activity followed by two days "rest" each week. Flow is still less than 25% of the original design estimate (of 10,000 gpd), but this has had no adverse effect on performance.

Effluent from the batch reactor, which consistently exceeds secondary standards, is polished in a pressure sand filter and carbon column. After ultraviolet disinfection, this final effluent is held until needed in a large underground tank. From here, flushing water for all toilets and urinals in the building is drawn and distributed through a pressurized water system. Excess is irrigated onto grass plots as shown in Figure 2. Makeup water if needed can be drawn from the potable supply, through an air-gap, but this has never been required in over six years. Average recycle rate for the past three years has been just over 50 percent, as shown in Table 1. This rate is not controllable, but results from the mix of toilet and non-toilet use in the building. Every indication is that a higher recycle fraction could be accommodated but there has been no opportunity to test this opinion. The complete plant is diagrammed in Figure 3, and pictured in Figure 4.

During each cycle of fill-treat-settle and draw, which occurs in the main process tank, a fixed volume of sludge is drawn and pumped to the aerobic digester. Sludge digestion proceeds under aerobic conditions until volatile solids are stabilized.

Sludge production rate is variable, but on the average, digested sludge has been drawn every 9 or 10 weeks for contract hauling and disposal.

Each time sludge is drawn into the aerobic digester, the digester air supply is shut down for approximately one hour so that settling can take place and a volume of supernatant liquor is drawn off and returned to the holding tank.

Digester settling-percent, which refers to the height of settled solids in a 100 ml graduated cylinder after 30 minutes settling is used as the control parameter. Experience on this plant has shown that digester operation is satisfactory up to the time when digester settling-percent climbs to 95. When, for about 3 months, polyelectrolyte additions were not used in the main process, the sludge pumping intervals were reduced sharply until, just before the experiment was terminated, the interval between pumpings was down to ten (10) days. This was obviously not enough time to produce a stabilized sludge.

EFFLUENT CHARACTERISTICS

Monthly samples have been collected, analyzed and reported to the Ohio EPA continously since February 1975. Rather than burden this paper with all that data, Table 1 shows averages plus maximum and minimum values for BOD_5 and suspended solids for each of the six and one-half years of operation. The extreme values indicate that there was very little spread in observed performance during any of the twelve month periods, or from one year to another.

It should be noted that the influent flow values are based on a seven day weekly average. Since there was actually very little flow on most Saturdays and Sundays, the typical weekday flow was probably closer to 7/5 of the values shown or for example:

$$\frac{(1700 \times 7)}{5} = 2380 \text{ Gals.}$$

This is not quite one fourth the nominal design rating of the plant (10,000 GPD). Experience indicates that the plant definitely has reserve capacity though it is doubtful if it could handle four times present load without additional capacity in the holding tank, sand filter, and influent pumping station.

The low BOD_5 and suspended solids values illustrate the effectiveness of this system in providing effluent consistently acceptable for re-use as flushing water or for spray irrigation.

The aesthetic qualities of the polished effluent were characterized by measurement of turbidity, color and odor. Subjective evaluation by the user population seemed to correspond reasonably well with these analytical parameters. It has been found desirable to change the contents of the carbon column every 12 to 16 months. The sand has been changed only twice during 6 1/2 years, both times as a result of operator error.

There was one serious complaint from a restroom where several users became very upset by odors. When the complaint was investigated there was indeed an odor. However, it had nothing to do with the SBR plant after all, but was originating from an infrequently used floor drain, from which the trap seal had evaporated.

OPERATION AND MAINTENANCE

The plant has been under the overall surveilance of Eaton's corporate environmental engineering staff, which is headquartered at this location. This has made it easy to obtain detailed and accurate reports of performance and any operating problems. Daily operation of the plant has been delegated to maintenance personnel, who spend an average of 15 to 20 minutes in routine housekeeping, lubrication, observation of pumps, seals, etc. and recording of basic data. The sand filter is manually backwashed daily and the carbon column once per week. The polyelectrolyte storage tank is refilled about once per month.

The polyelectrolyte used is a long chain, high-molecular weight cationic polymer equivalent to Dow C-31, which is fed at a concentration of approximately 20/mg/l after dilution from a storage concentration of 50% to a feed concentration of 2-4%.

One significant problem was originally encountered with the plant. Frequently, the settled sludge would rise before the clear supernatant was completely pumped from the process tank. This would produce high levels of solids in the secondary effluent and rapid plugging of the sand filter.

While these episodes of rising sludge were a serious operating problem, they never had an adverse effect on final effluent quality because the process is so well guarded by tertiary steps.

Analysis of the operation of the main process tank revealed that nitrogen gas bubbles were the culprit. Nitrifying bacteria, nitrosomonas and nitrobacter , convert the ammonia in sewage to nitrites ($-NO_2$) and nitrates ($-NO_3$) during the aeration period. This is called nitrification. When the air is turned off during the settling period anoxic denitrification occurs. A broad range of bacteria reduce the nitrates during denitrification which produces free nitrogen gas. If this anoxic condition is sufficiently prolonged, enough nitrogen gas accumulates in the settled sludge to cause it to rise to the surface.

It was believed that preventing nitrification in the first place would offer a solution to the problem since denitrification, by definition, cannot occur without prior nitrification.

Several methods of nitrification prevention such as pH or Dissolved Oxygen control are discussed in the literature(16). However, because very precise control of either of these parameters was required, another method appeared to offer more promise in this application; namely the use of a chemical to inhibit the nitrification process. This method has been used for the fixation of fertilizers on croplands.

In normal agricultural usage, bacteria in soil convert the ammonia in fertilizer to nitrates. The very soluble nitrates are then washed rapidly into (or off of) the soil by rain or irrigation water. A chemical, TCMP (2-chlor-6- [trichloromethyl] pyridine), has been used successfully to prevent too rapid conversion of ammonia in fertilizer to nitrates. This extends the useful life of the fertilizer significantly.

It was postulated that the same chemical (TCMP) could retard nitrification in the process tank of the SBR wastewater treatment system. So, beginning in June 1979, introduction of TCMP into the process tank was started on an experimental basis. Each time the inlet grinder pumps ran, TCMP was fed, at a rate of 1 to 2 ppm, into the process tank simultaneously with the raw sewage. The rising sludge problem almost immediately disappeared, and analysis of the secondary effluent showed that nitrification inhibition was being accomplished. Nitrate levels prior to addition of TCMP had ranged between 30 and 50 ppm. After TCMP addition began, nitrate levels averaged far below 5 ppm and never exceeded 10.

During the next few months nitrate levels remained low, effluent quality remained high, and there were no episodes of rising sludge. Then in October 1979 TCMP addition was stopped by a failure of the chemical feed pump. Contrary to our expectations, however, nitrate levels remained low and there were no problems with rising sludge. A possible explanation for this was that TCMP had been absorbed by the carbon column earlier and was now leaching back out and being reintroduced into the process tank through the recycled water.

This hypothesis was tested by temporarily by-passing the carbon column for a few days. By way of confirmation, nitrate levels began rising immediately. At this point the TCMP feed pump was restarted and the carbon column placed back on stream.

The addition of TCMP to the process tank has very successfully controlled rising or "bulking" sludge. The chemical feed pump has caused some difficulty by failing periodically because it is not very resistant to the xylene in which the TCMP is dissolved. The search for a suitable pump continues, so far unsuccessfully. These periodic pump failures have in every instance been signaled by rising sludge soon thereafter.

MECHANICAL CONSIDERATIONS

Based on over six years of operating experience , a number of observations have been made including the following:

1. The overall equipment reliability has been very good.
2. Pumps are of appropriate size and very dependable.
3. Air supply is more than adequate for the present loading conditions.
4. Grinder pumps, though rated for three or four times less daily flow, have performed satisfactorily. Stator life is about as expected, based on hydraulic loading recommended by the manufacturer. Significant improvement was noted in the stator life of these pumps when level controls were adjusted to avoid any possibility of a dry running condition.
5. The pumps and valving through the tertiary system were altered slightly so that it is impossible for effluent to pass out of the system without at least one pass through the carbon column. This assures high quality effluent even during short periods of peak flow.
6. Primary user of electric energy has been the 5hp blower motor, which runs continuously. Other pumps and controls which operate for a few minutes each cycle, bring the total equivalent electric load to about 6 1/2hp. At a power factor of 0.8, this is equivalent to just over 6 KW-hr per hour, or less than $9.00 per day for power.
7. Early in the operation of the plant, after an extended period of trouble shooting, it was discovered that the sludge pump was air locking due to its suction piping configuration and location. When this was corrected, the solids in the main process tank dropped from excessively high values to normal, and performance has been satisfactory since.
8. It is recommended that in future sequencing batch reactor plants the control panel be modified so that access to the test points may be had for electrical trouble shooting without power being turned off by a main safety interlock. This is a good example of well intentioned safety measures being taken to such extremes that legitimate operating functions are precluded. It was also found that some mechanical cycle timers were difficult to set to the precise accuracy needed and an improved solid state model is being currently evaluated.

CONCLUSIONS

1. Final effluent quality has been consistently outstanding and the Ohio EPA has commented favorably and publicly on the Environment/One Sequencing Batch Reactor (SBR) plant as installed at, and operated by, the Eaton Corporation.
2. An original tendancy toward frequent sludge bulking was successfully eliminated through use of a nitrification inhibiting chemical (TCMP).

3. Recycle of over 50% of the treated waste stream for toilet flushing has been practiced successfully for over six years. Acceptance by the user population was almost immediate and has long ago become a "ho-hum" matter.

DISCLAIMER

The information contained in this paper is intended as a general description of the operation of a specific waste treatment system. It is not intended to replace or serve as the basis for the actual design of any waste treatment system. It is also not intended to be the basis for establishing procedures for complying with any state or federal environmental regulations. The authors and their employers expressly disclaim any responsibility whatsoever for any designs, studies or compliance strategies based on any part of this paper.

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12. Ardern, E. and Lockett, W.T., "The Oxidation of Sewage Without the Aid of Filters", Jour, Soc. Chem. Ind., 34,937 (1915).

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14. Farrell, R. P., Jr. U.S. Patent 3,841,998 "Aerobic Wastewater Treatment Process with Partial Reuse and Infrequent Dosing to Soil", October 15, 1974.

15. Farrell, R. P., Jr. and Setser, James L. U.S. Patent 3,920,550 "Process and Equipment for Automatic Chemical - Biological Wastewater Treatment with Provisions for Recycle and Reuse". Nov. 18, 1975.

16. Anon , "Process Design Manual for Nitrogen Control", U.S. EPA - Technology Transfer, October, 1975.

TABLE 1: PERFORMANCE DATA FOR SEQUENCING BATCH REACTOR WASTEWATER IS SANITARY WASTE

		1975	1976	1977	1978	1979	1980	1981(3)
FLOW								
TOTAL, GPD	AVE.	1700	1625	1600	1569(2)	2097	2004	1903
TO IRRIGATION, GPD	AVE.	(1)	(1)	(1)	780(2)	991	1136	793
RECYCLE PERCENT	AVE.	-	-	-	50.3(2)	52.7	43.3	58.3
INFLUENT								
BOD_5, mg/l	AVE.	287	260	399	208	322	313	228
	MAX.	650	425	675	330	650	460	280
	MIN.	80	90	115	35	180	180	170
S.S., mg/l	AVE.	765	478	327	308	442	785	263
	MAX.	1900	1100	720	400	1100	3300	420
	MIN.	250	150	140	220	180	160	160
EFFLUENT								
BOD_5, mg/l	AVE.	2.5	3.1	3.7	8.3	2.0	6.5	7.0
	MAX.	7.0	7.0	7.0	15.0	6.0	31.0	15.0
	MIN.	1.0	1.0	1.0	4.0	1.0	1.0	2.0
S.S., mg/l	AVE.	7.8	1.3	1.6	2.7	8.0	7.2	5.7
	MAX.	24.0	3.0	5.0	11.0	3.8	23.0	9.0
	MIN.	1.0	1.0	0	1.0	1.0	2.0	2.0
AVERAGE ANNUAL PERCENT, REMOVAL.								
BOD_5 - %		99.1	98.8	99.1	96.0	99.3	97.9	96.9
S.S. - %		99.0	99.7	99.5	99.1	98.2	99.1	97.8

1) Data Not Available, (2) 5 Months Data, (3) 4 Months Data

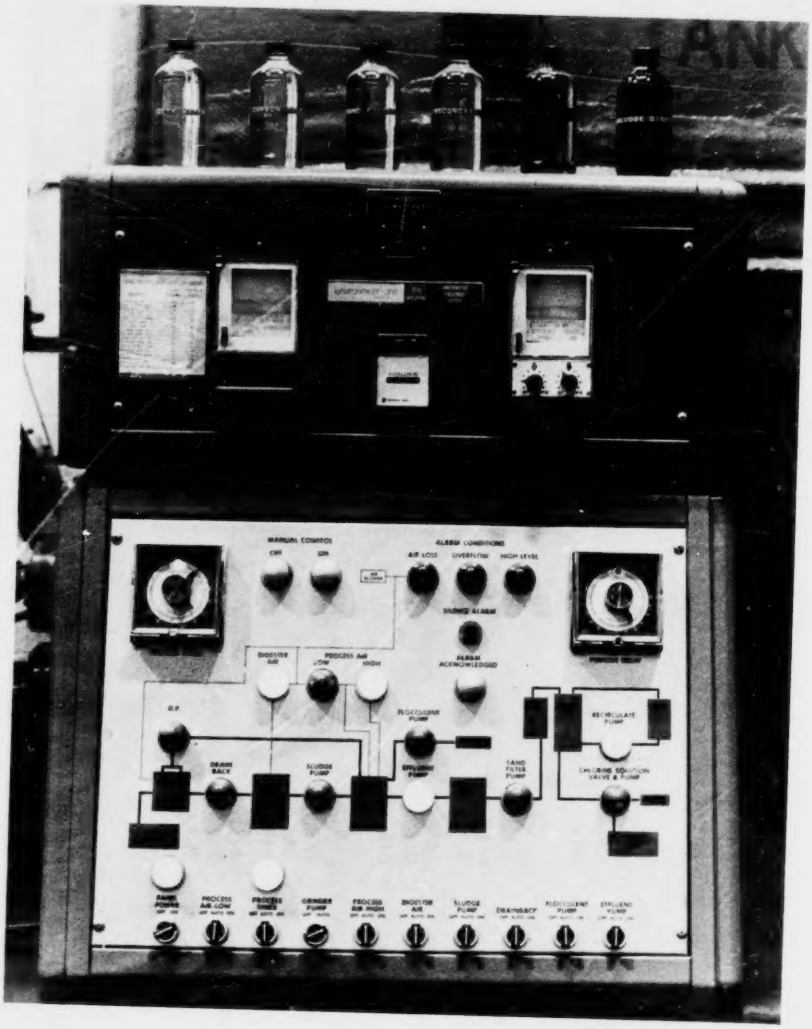

MANUAL CONTROL
OFF
ON
ALARM CONDITIONS
AIR LOSS
OVERFLOW
HIGH LEVEL
ALARM ACKNOWLEDGED
DIGESTER AIR
PROCESS AIR
LOW
HIGH
FLOCCULENT PUMP
RECIRCULATE PUMP
DRAIN BACK
SLUDGE PUMP
EFFLUENT PUMP
SAND FILTER PUMP
CHLORINE SOLUTION VALVE & PUMP
PANEL POWER
PROCESS AIR-LOW
GRINDER PUMP
PROCESS AIR HIGH
DIGESTER AIR
SLUDGE PUMP
DRAINBACK
FLOCCULENT PUMP
EFFLUENT PUMP

Figure 1 - Panel for Automatic Sequencing Control of Batch Reactor Treatment Plant furnished by Environment One Corp.

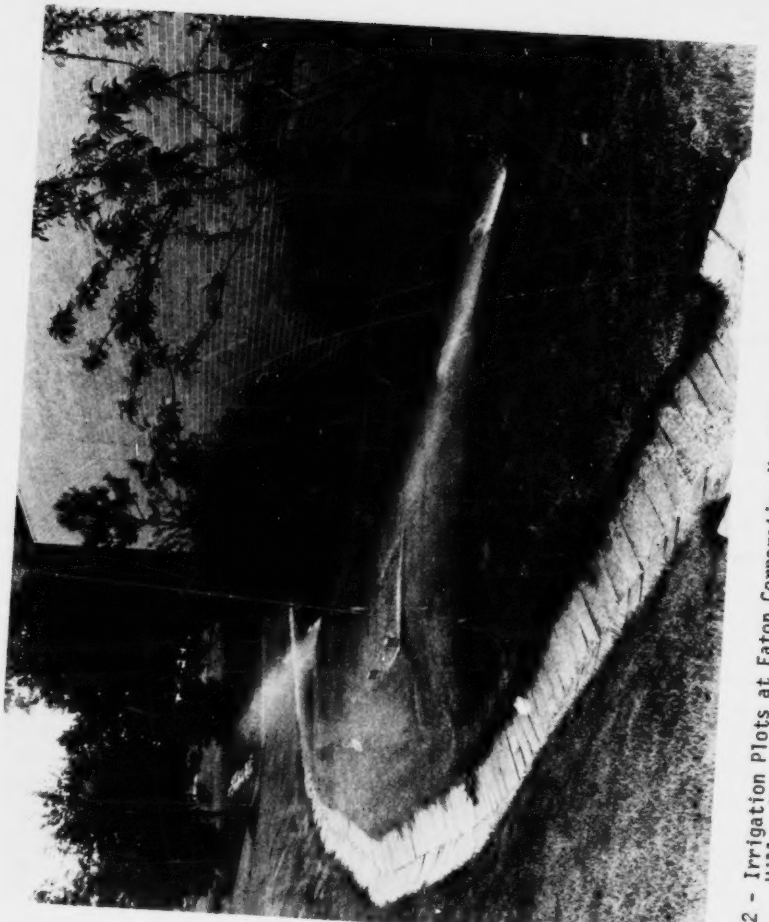


Figure 2 - Irrigation Plots at Eaton Corporation Manufacturing Services Center - Willoughby Hills, Ohio

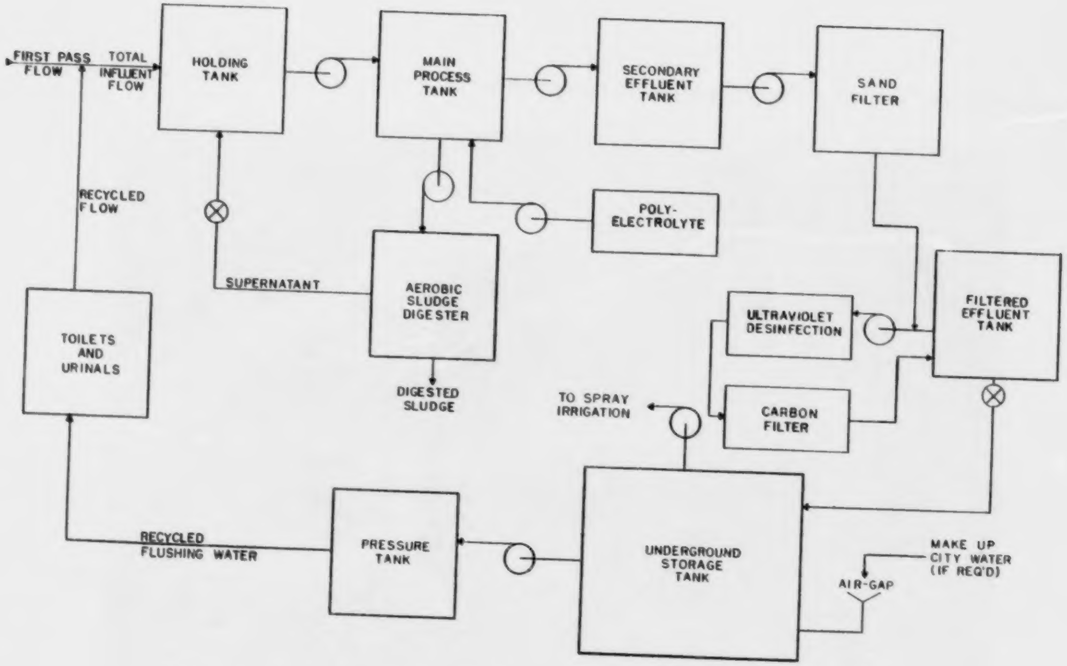

FIRST PASS FLOW
TOTAL INFLUENT FLOW
HOLDING TANK
MAIN PROCESS TANK
SECONDARY EFFLUENT TANK
SAND FILTER
RECYCLED FLOW
POLY-ELECTROLYTE
SUPERNATANT
AEROBIC SLUDGE DIGESTER
TOILETS AND URINALS
DIGESTED SLUDGE
ULTRAVIOLET DESINFECTION
FILTERED EFFLUENT TANK
TO SPRAY IRRIGATION
CARBON FILTER
RECYCLED FLUSHING WATER
PRESSURE TANK
UNDERGROUND STORAGE TANK
MAKE UP CITY WATER (IF REQ'D)
AIR-GAP

Figure 3 - Flow Chart - Environment One Sequencing Batch Reactor (SBR) Treatment Plant

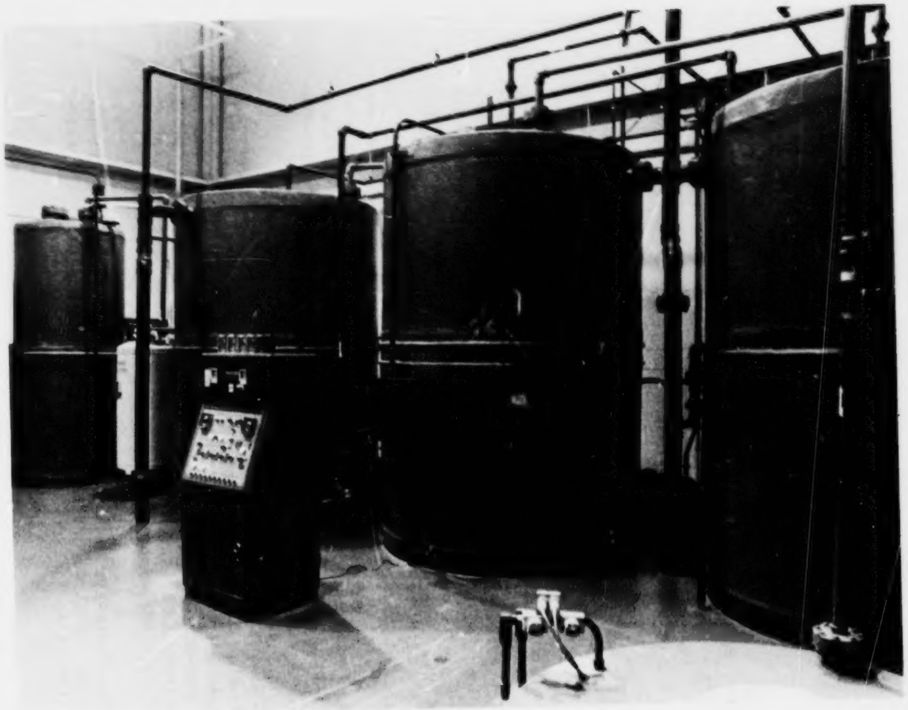


Figure 4 - Overall View of Sequencing Batch Reactor (SBR) at Eaton Corporation, Willoughby Hills, Ohio

PB82-223264

SUBSURFACE GROUNDWATER RESERVOIR FOR THE CITY OF NEWARK, DELAWARE: A CONCEPT FOR WATER SALVAGE

Dudley L. Willis, P.E.

Edward H. Richardson Associates, Inc.
A Tetra Tech Company
Engineers, Architects, Planners,
Landscape Architects, Surveyors,
Environmental Scientists
P.O. Box 675
Newark, Delaware 19711

and

Resource Recovery, Inc.
108 Briar Lane
Newark, Delaware 19711

INTRODUCTION:

The groundwater supply for Newark, Delaware has proven to be inadequate; and, as the design for a conventional dam and impoundment reservoir on the White Clay Creek has become politically and environmentally unacceptable, it appears to be important to identify alternate sources of good water that are politically practical and economically feasible for development. Also, it is important to determine whether or not there are viable alternative techniques whereby an unconventional or innovative approach to water acquisition and storage is justified.

It appears that at least one significant technique for water salvage and storage has been overlooked. This would be to form huge subsurface water storage reservoirs in the ancient gravel-filled river channels and in the piedmont alluvial gravel deposits. Such reservoirs would function and be operated in much the same manner as conventional dammed reservoirs and tank reservoirs now are.

They would differ from conventional practice in that the reservoir would be contained by a flexible wall of grout injected into natural sand and gravel deposits. These walls would be thin and impervious and would depend upon the adjacent in situ soils for restraint and structural support.

Water would be stored in the natural soil voids and the reservoirs would be sized so as to be capable of leveling out water supply fluctuations over seasons or years rather than on a daily or weekly basis. The reservoir system would be designed to salvage groundwater which would otherwise pass the site on its way to being lost into brackish or salt waters of the river or bay.

Storage would be created by backing up water so as to raise the groundwater elevation in existing aquifers or by pumping into an artificially restrained portion of an aquifer.

DISCUSSION:

As an aid in understanding the concept of subsurface dams and reservoirs, a brief and simple description of the geological activities which shaped the Delaware region is given. What has happened here has happened in many other locations throughout the world, and concepts illustrated here can be practiced in many areas.

During relatively recent geological times the world, as we know it, was shaped by the erosion of high mountains and the deposition of various types of sediments. However, when and where the rock was protected by a sea water cover there was little erosion; and the basic rock forms the floor on which unmodified sedimentary soil deposits lie (Fig. 1). The top of this basement rock varies from ground surface level near Newark to almost eight thousand feet deep at the southeast corner of the State of Delaware.

Following the earlier periods of land formation, there were many major variations in sea level, and sedimentary action related to these is generally associated with one of three major geological periods: the CRETACEOUS PERIOD--which saw the end of the dinosaurs; the TERTIARY PERIOD--during which deposits in the Delaware region were dominantly laid down in sea or bay water; and the QUATERNARY PERIOD--which covers the last one-half to one million years. The Quaternary is the period of activity during which the deposits discussed in this paper were formed.

Within the Quaternary period there were at least four major advances and retreats of the glaciers, during which the sea level varied from approximately three hundred feet below its present level to approximately one hundred feet above.

During each period of maximum glacial advance, the sea level was at its lowest; and, as glacial thaw progressed, the melt water carved deep channels as it fell toward the sea. Then, as the sea level rose, the channels were gradually drowned and buried by debris. This debris forms the area's water supplying aquifers and furnishes sand and gravel for construction.

Four of the drowned channels are identified on exhibits of the Delaware Geological Survey, and one of these exhibits has been modified to show how subsurface dams and reservoirs could be used to improve the harvest and storage of major groundwater supplies which are now harvestable in limited quantities as they flow past the area of need on their way to points of lower drawoff--or, are lost to subsurface discharge into the river or bay.

It appears that the natural sand and gravel deposits could be used so as to create a northern Delaware reservoir, approximately fourteen miles long and up to one and one-quarter miles wide, held back by a series of subsurface dams which control the surface of the groundwater with respect to the land surface. Also, it appears that there could be a reservoir at a deeper level which would also store an enormous quantity of water. However, in order to simplify the illustration, only portions of the potential high-level reservoirs are shown (Fig. 2).

Admittedly, the channels are far more complex than shown, and there are many minor connecting channels so that each aquifer is not necessarily isolated from adjacent ones. However, each proposed site could be defined, and its serviceability evaluated, by use of subsurface soils exploration.

Unusual aspects of the proposed reservoirs are:

1. There would be no relocations, damages, or inconveniences to local residents such as flooding of roads, farms, or home sites.
2. There would be very small losses of reservoir water due to evaporation.

3. One reservoir might lie so as to partly overlay another.
4. Very few people would realize that such huge reservoirs existed or be aware of their construction. Reservoirs would essentially occupy "free" land.
5. There would be no reservoir excavation or open water surface as the reservoir's maximum water surface elevation would be several feet below the natural ground surface.
6. The dam, or reservoir wall, would be elastic, only a few feet thick, and relatively inexpensive when compared to its massive structural concrete counterpart.
7. Only 20 to 40 percent of the volume of the reservoir would be available for storage as the balance would be occupied by native gravels and sands, and their associated silts and clays.
8. There would be no harm to or displacement of native flora or fauna--no major adverse environment impact.

PROPOSED PROJECT:

On a smaller scale, a walled reservoir could be constructed in the alluvial deposits so as to provide local storage of water which would normally pass the the area as seasonal excess flow or as sheet-flow so shallow as to not warrant salvage.

The Edward H. Richardson Associates, Inc., office building lies adjacent to a City of Newark well-field where the alluvial deposits are approximately eighty feet deep, and the seasonal water levels in this aquifer severely restrict the usable water supply during dry seasons.

It is proposed to encircle the building and its parking lot with a prototype reservoir so as to demonstrate salvage and storage of transient waters for use during prolonged periods of water shortage (Fig. 3).

The sidewalls for the subsurface reservoir would be constructed as a flexible membrane grouted into place and restrained by the native soils adjacent to the soil into which the grout is injected. Subsurface vibratory compaction would be used at the same time so as to provide maximum soil density, reduce the potential for settlement and displacement, and require a minimum amount of grout.

Wells in the existing City of Newark well-field would be used to fill the reservoir when excess water is available, and water from the subsurface reservoir would later be recycled out through the existing aerators and ground level reservoirs.

On a larger or optimum size operation, it would be desirable to divert excess water from the Christina River for filling of the subsurface reservoir. However, a prototype installation approximately one hundred feet in diameter should be a reasonable start on concept development. A reservoir of this size would be of immediate value to the City and large enough for evaluation of construction cost and development of design and operation criteria for a similar system whch is large enough for seasonal or yearly leveling of the City's water supply needs.

Study will be required in order to determine whether or not water would benefit from treatment prior to subsurface storage. This is also true in order to determine cost effectiveness of treatment both prior to and following storage. This, and many other facets of both a technical and legal nature would be incorporated into the proposed study, design, installation and operation.

CONCEPT EXTENSIONS:

The geological conditions which make the concept applicable to coastal Delaware occurred world-wide, and the most valuable application of the concept may be in our water-poor states or other arid parts of the world where the damming of old stream channels would build up the depth and capacity of the groundwater supplies. At the same time, it could reduce fresh-water losses to the sea or reduce the areas in which a high rate of evaporation builds up salt or alkaline surface deposits.

Figure 4 shows a cross section, highly stylized, through the Sultanate of Oman. Here the high mountains pitch rapidly into the sea on the east, while on the west they disappear into the desert on the "empty quarter" of Saudi Arabia. Such places offer unlimited opportunities for use of subsurface damming and its variations. It is possible that the development of major water resources could create favorable long-term environmental and economic impacts far greater than those now created by currently critical oil resources.

CONCLUSIONS:

Enhancement of water supply resources and economy of reservoir construction may appear to be the best arguments in favor of building subsurface reservoirs. Yet, there are equally good public health reasons as the subsurface reservoirs cannot harbor the mosquitoes, flies, and snails that carry disease and blindness throughout many parts of the world.

Only extensive geological studies and carefully controlled pilot projects will prove the real worth of this concept, and a subsurface reservoir for the City of Newark should be an excellent prototype project.

ACKNOWLEDGEMENTS:

Early publications of the Delaware Geological Survey were of tremendous assistance and lent technical support and geological history to the development of the concept for subsurface water storage.

Valuable personal support and encouragement has been given by both Robert D. Varrin, Ph.D., of the University of Delaware, and Johan J. Groot, Ph.D., former Delaware State Geologist, now a practicing groundwater resources consultant.

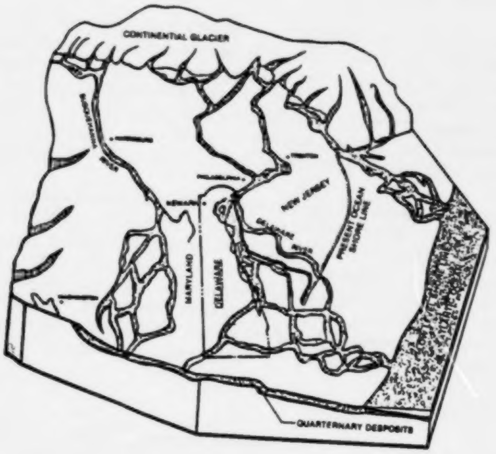

CONTINENTAL GLACIER
NEW JERSEY
PRESENT OCEAN SHORE LINE
DELAWARE RIVER
MARYLAND
DELAWARE
QUARTERNARY DESPOSITS

Figure 1

Geological Block Diagram of Delaware
During Glacial Times

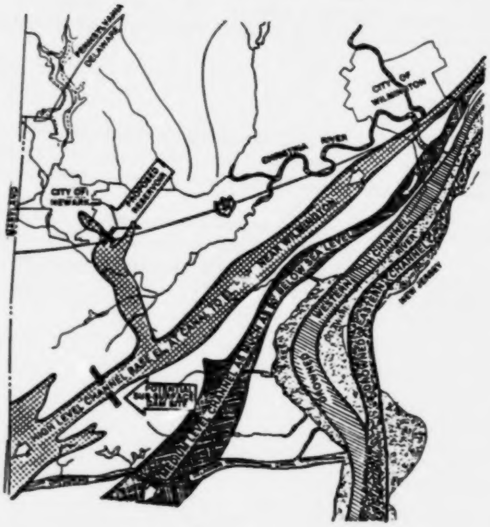

PENNSYLVANIA
DELAWARE
CITY OF WILMINGTON
CHRISTINA RIVER
CITY OF NEWARK
PROPOSED RESERVOIR
HIGH LEVEL CHANNEL
BELOW SEA LEVEL
WESTERN CHANNEL
EASTERN CHANNEL
DELAWARE RIVER
NEW JERSEY

Figure 2

Buried and Drowned Channels in Coastal
Plains of Northern Delaware

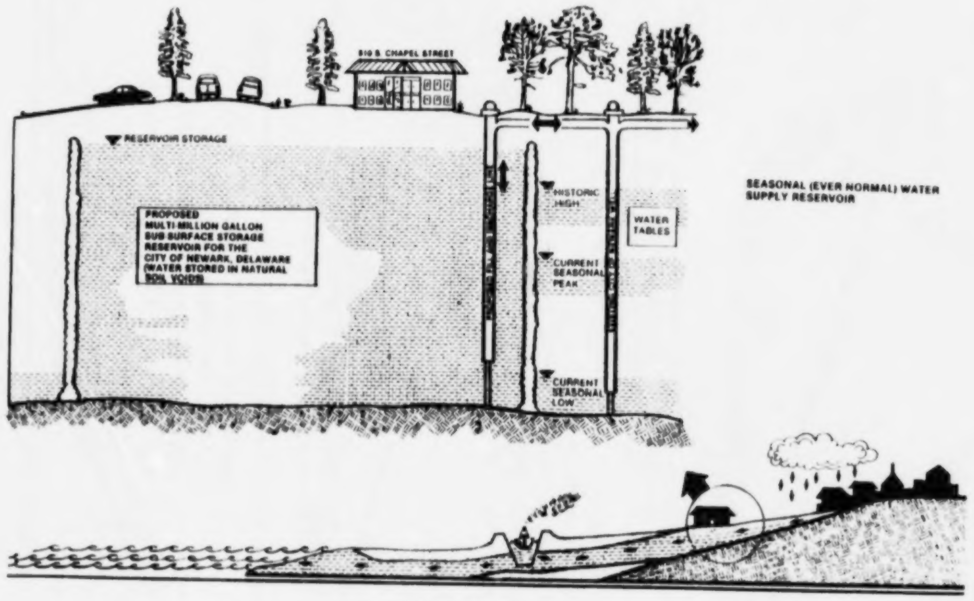

510 S. CHAPEL STREET
RESERVOIR STORAGE
PROPOSED
MULTI-MILLION GALLON
SUB SURFACE STORAGE
RESERVOIR FOR THE
CITY OF NEWARK, DELAWARE
(WATER STORED IN NATURAL
SOIL VOIDS)
HISTORIC
HIGH
CURRENT
SEASONAL
PEAK
CURRENT
SEASONAL
LOW
WATER
TABLES
SEASONAL (EVER NORMAL) WATER
SUPPLY RESERVOIR

Figure 3

Seasonal (Ever Normal) Water Supply Reservoir

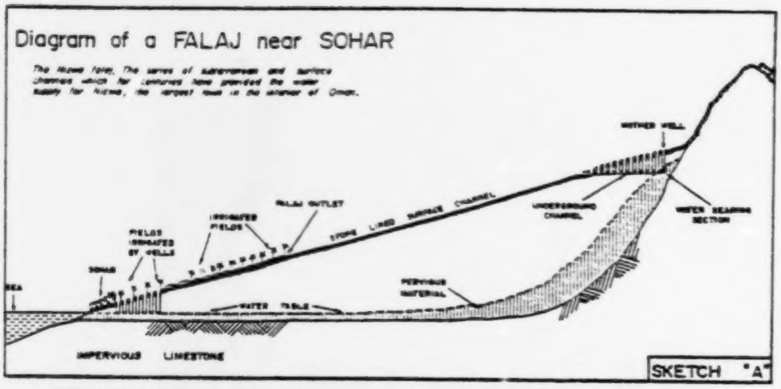
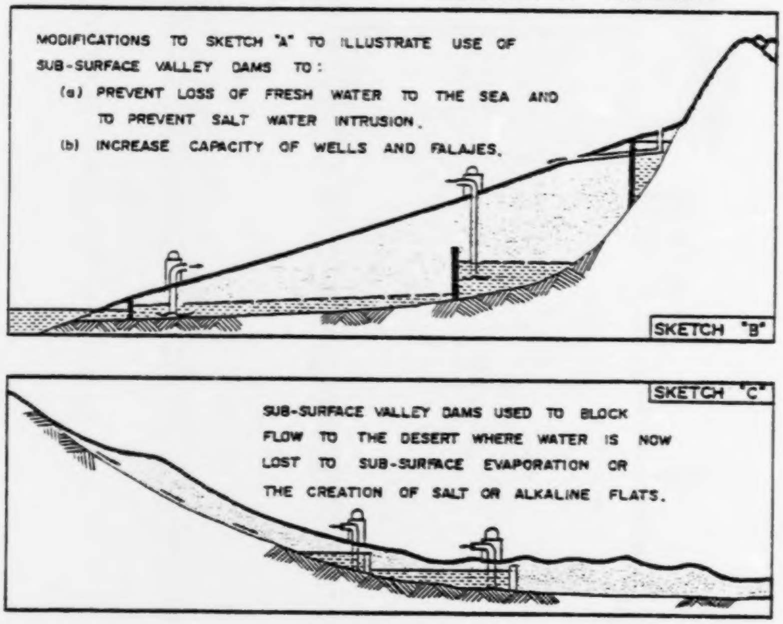


Diagram of a FALAJ near SOHAR
MOTHER WELL
UNDERGROUND CHANNEL
WATER BEARING SECTION
FALAJ OUTLET
STONE LINED SURFACE CHANNEL
IRRIGATED FIELDS
FIELDS IRRIGATED BY WELLS
SOHAR
SEA
PERVIOUS MATERIAL
WATER TABLE
IMPERVIOUS LIMESTONE
SKETCH "A"

THE ABOVE SKETCH FROM: "SULTANATE OF OMAN - HISTORY AND ARCHAELOGY"


SKETCH "B"
SKETCH "C"

MODIFICATIONS TO SKETCH "A" TO ILLUSTRATE USE OF SUB-SURFACE VALLEY DAMS TO:

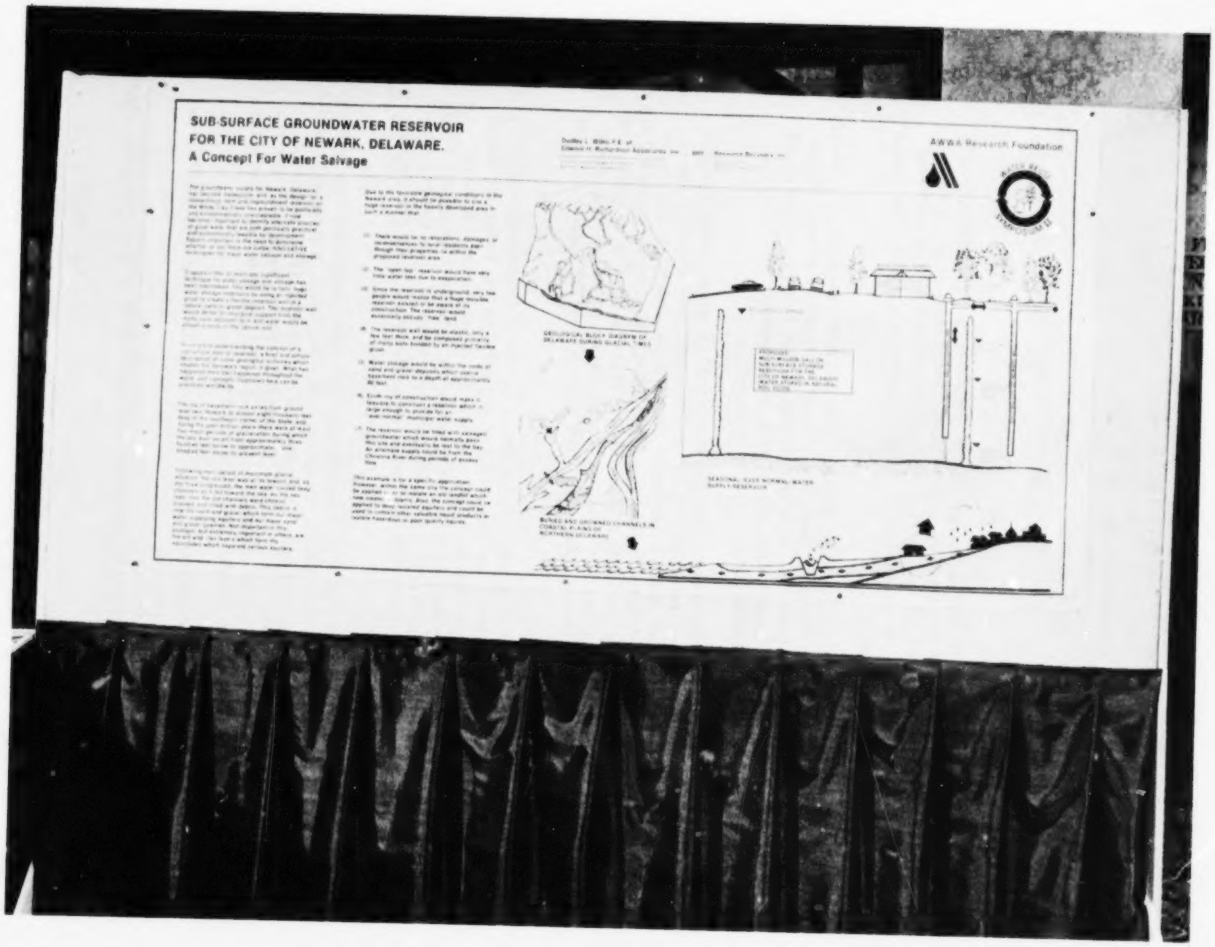
(a) PREVENT LOSS OF FRESH WATER TO THE SEA AND TO PREVENT SALT WATER INTRUSION.

(b) INCREASE CAPACITY OF WELLS AND FALAJES.

SUB-SURFACE VALLEY DAMS USED TO BLOCK FLOW TO THE DESERT WHERE WATER IS NOW LOST TO SUB-SURFACE EVAPORATION OR THE CREATION OF SALT OR ALKALINE FLATS.

Figure 4

Sub-Surface Dam Concepts as Applied
To Water Resources of Sultanate of Oman



SUB-SURFACE GROUNDWATER RESERVOIR FOR THE CITY OF NEWARK, DELAWARE.

A Concept For Water Salvage

AWWA Research Foundation
GEOLOGICAL BLOCK DIAGRAM OF DELAWARE DURING GLACIAL TIMES
BURIED AND DROWNED CHANNELS IN COASTAL PLAINS OF NORTHERN DELAWARE
SEASONAL OVER NORMAL WATER SUPPLY RESERVOIR

CITY OF SPRINGFIELD, ILLINOIS, AUXILIARY WATER SUPPLY SYSTEM

David K. Wyness
Associate
Crawford, Murphy & Tilly, Inc.
2750 West Washington Street
Springfield, Illinois 62702

INTRODUCTION

Although portions of the Sangamon River in Central Illinois contain significant amounts of treated wastewater, extensive studies have developed an economical and energy-efficient procedure to pretreat this water for use as an auxiliary water supply system in the state's capital, Springfield.

Lake Springfield, a 17 billion gallon (64,362,000 cubic meter) reservoir, is the source for the municipal water treatment plant, which processes potable water for 140,000 people. The lake also supplies process and cooling water for the city's 400-megawatt coal-fired electric generating station.

Because of increasing demand for these municipal uses, Lake Springfield's drought-yield capacity of 17 million gallons (64,362 cubic meters) per day is no longer adequate to provide the safe raw water. During the past 15 years, numerous engineering studies have indicated that the city should construct another 17 billion gallon (64,362,000 cubic meter) lake to satisfy the projected water needs of the city. In terms of 1980 dollars, however, this option was estimated to cost $38 million.

Consequently, the city hired consulting engineers Crawford, Murphy & Tilly, Inc. to evaluate the feasibility of developing indirect water reuse procedures with nearby river waters as a supplemental water supply. During drought periods, the Sangamon River would yield about 50 million gallons (189,292 cubic meters) per day of raw water, with 75 percent of that water consisting of treated municipal and industrial waste waters.

A unique concept was developed which economically utilizes innovative and energy-efficient equipment while maximizing local topography and natural hydraulic conditions. The system would entail construction of a low-level diversion structure to impound river waters. The impounded water would be processed with helical-flow reactor clarifiers to almost-acceptable potable water standards.

This processed water would be discharged into Lake Springfield so as to blend naturally with the lake water. Eventually, the water would be treated again at the city's lime-softening and filtration plant. The estimated cost for this pretreatment method is $13 million in 1980 dollars, or about one-third the cost of a new lake.

PILOT PLANT STUDIES

A six-month bench scale study and pilot plant investigation were conducted as a joint effort by Springfield's City Water, Light & Power, the Illinois Environmental Protection Agency and Crawford, Murphy &

Tilly, Inc. Flow conditions during the study period, if projected, would match those of a severe drought.

It is projected that at the beginning of a drought occurring in the year 2000, 1 percent of the lake's contents will have originated in wastewater effluent from sewage treatment plants. Under drought conditions in the year 2000, it is estimated that the Sangamon River will have a content of 36.5 percent wastewater. The remaining water will be from surface runoff or supplemental groundwater.

These estimates are based upon the assumption that the critical period for a severe drought is 18 months and that the water in the lake at the beginning of the drought would be 1 foot (0.3 meters) below spillway level. At the end of the drought, given a 75 percent wastewater content for the Sangamon River, the lake would have a wastewater content of 38.1 percent. This percentage is based upon the assumption that there will be complete mixing of the lake's contents.

Operation of the pilot plant began on September 23, 1980, and ended November 7, 1980. The pilot plant studies had three objectives: (1) to determine applicability of the pretreatment process using the helical-flow reactor clarifier for clarifying raw river water, (2) to determine the degree of contaminant removal that could be expected from the proposed pretreatment facilities, and (3) to determine the effectiveness of chlorine and chlorine dioxide for disinfection.

The pilot plant was an 8-foot (2.4 meter) diameter ClariCone helical-flow reactor clarifier supplied by Walker Process of Aurora, Illinois. River water was pumped through the clarifier at an average rate of 15 gallons (5.2 liters) per minute. Aluminum sulfate was added as a coagulant, and powdered activated carbon was added to absorb organic compounds. Chlorine dioxide and later chlorine were fed above the sludge blanket for disinfection. In some cases, the clarifier was operated without a disinfectant.

Prior to and during pilot studies, samples were taken from tributary waters of Lake Springfield and from the Sangamon River and its tributaries. Analyses from normal water quality components were made by Crawford, Murphy & Tilly's laboratory. The Illinois EPA made analyses for virus determination and for pesticides, herbicides and other organic compounds. Heavy metal analyses of the river were already available from Illinois EPA records. The Springfield water treatment plant performed examinations for parasites in its laboratory.

During pilot plant operations, comparisons were made of this data in raw Sangamon River water and treated effluent from the pilot plant. Chemically and bacteriologically, the pretreated water met EPA potable water standards. From 90 to 99 percent of the macro-organisms were removed, even though the process did not include filtration. Results of water quality analyses are provided in Tables 1 and 2.

PROPOSED PRETREATMENT FACILITIES

Studies have indicated that topographical features are such that a dam across the channel of the Sangamon River, just downstream from one of its tributaries, will permit water to be backed up to an existing pumping station. Modification of the existing pumping station will permit water to be pumped to new pretreatment facilities for discharge into Lake Springfield (Fig. 1). Estimates of the flow availability during drought conditions show that there will be adequate flow to provide the estimated water needs of Springfield and to permit release of an average 13.2 million gallons (59,975 cubic meters) of water per day to downstream users.

The proposed pretreatment facilities consist of six helical-flow reactor clarifiers, several chemical storage areas, control and chemical feed building, sludge lagoon and sludge farm (Fig. 2). Each clarifier is to be 51.6 feet (15.48 meters) in diameter.

The helical-flow clarifier was designed to achieve stoichiometric efficiency, produce a low turbidity effluent water and to be simple to operate and maintain. The primary design concept was to develop a reaction vessel that could maintain and control a highly dense, dynamic sludge blanket. A hydraulically-driven system was designed to form and maintain a rotating conical-shaped sludge blanket through which water would flow upward in an expanding helical path. This design eliminates mechanical problems and minimizes the energy input required to maintain the sludge blanket. A preliminary section of the clarifier and the control building are contained in Fig. 3.

Studies have recommended that, after the proposed facilities are in place, pumping and pretreatment should begin whenever the water level of Lake Springfield recedes more than 1 to 1½ feet (0.3 to 0.45 meters) below spillway level. The studies further recommended that the facilities be used at least two or three months each year to keep the lake near spillway level, to keep the equipment in good operating condition and to keep personnel familiar with operating conditions.

CONCLUSIONS

The Sangamon River plan is an "indirect" wastewater reuse procedure. Such a system is less hazardous than a "direct" reuse system, where wastewater treatment plant effluent is taken directly to a plant for potable water treatment.

There is a significant amount of travel time involved in flow of the Sangamon River from the wastewater sources to the point at which the water would be pumped into the lake. The largest wastewater source is a municipality 40 miles upstream from the proposed diversion site. Given the long travel time of two days, a certain amount of self-cleansing of the water will take place as a result of natural aerobic conditions and volatization of some pollutants. In addition, the "indirect" water reuse method will utilize available storage in Lake Springfield, the Sangamon River and its tributaries.

ACKNOWLEDGEMENTS

Crawford, Murphy & Tilly, Inc. wishes to acknowledge City Water, Light & Power, the Illinois EPA, the Illinois State Water Survey, and the Illinois Department of Public Health for their guidance and cooperation in this endeavor.

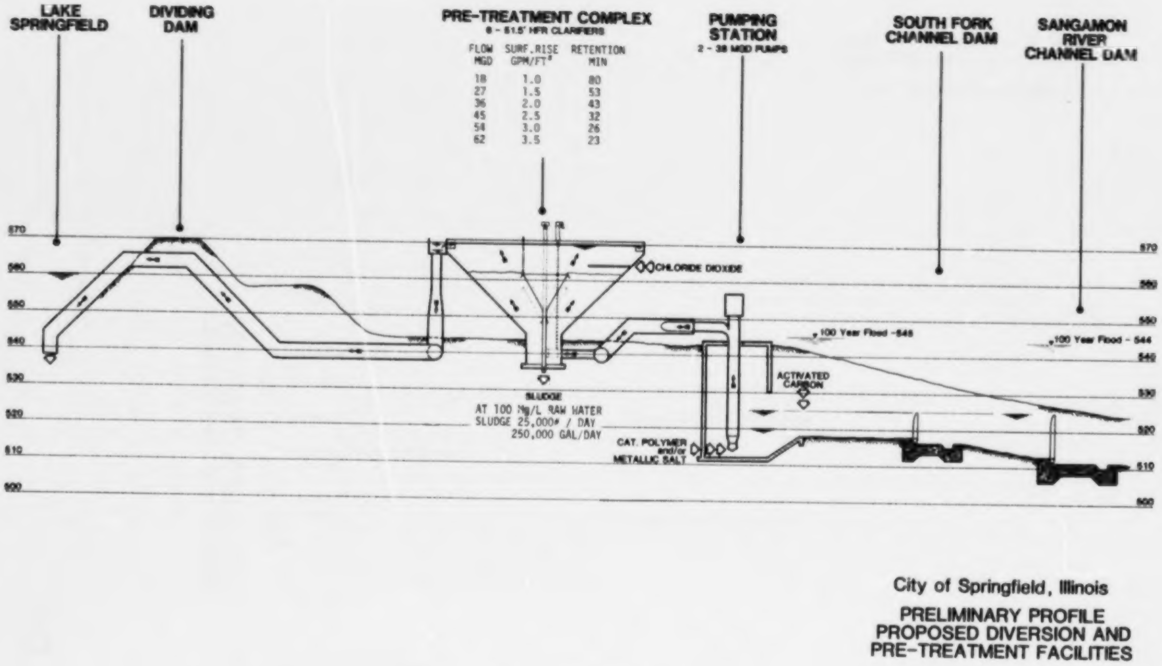
TABLE 1
SANGAMON RIVER ANALYSES DURING PILOT PLANT OPERATIONS

DATE	APPRCX. FLOW (MGD)	pH		TURBIDITY (NTU)		TOTAL ALKALINITY (mg/1 AS $CACO_3$)		TOTAL HARDNESS	CALCIUM (mg/1 AS $CACO_3$)	MAGNESIUM	CHLORIDE (mg/1)	SULFATE (mg/1)	ORTHO-PHOSPATE (mg/1)	ORTHO-PHOSPATE (mg/1)	NITRATE (mg/1 AS N)
		RAW	TREATED	RAW	TREATED	RAW	TREATED	RAW	RAW	RAW	RAW	RAW	RAW	TREATED	RAW
9/26/80	37	7.9	7.5	11	2.5	212	192	320	168	152	201		6.5	1.3	1.3
10/1/80	35	7.9	7.0	10	1.1	220	160				260		7.6	0.80	2.6
10/2/80	35	8.1	6.8	9.0	1.3		152				280		7.5	0.80	
10/3/80	35	8.1	7.0	7.6	2.0	222	176				270	155	6.5	1.0	0.8
10/6/80	35	7.9	6.7	7.3	1.4	216	144				280		6.0	1.1	
10/9/80	35	7.7	6.7	12	1.2	240	164				290	185	9.8	0.94	2.6
10/13/80	35	7.8	7.0	6.4	2.0						260				
10/14/80	35	7.8	6.8	7.9	1.9	220		284	160	124	290	180	9.7	0.96	1.0
10/15/80	35	7.8	6.8	8.0	1.5										
10/16/80	35	7.8	6.7	10.5	1.6										
10/17/80	39	7.8	6.8	16	1.8	204		270	155	115	275	185	11.5	1.2	2.6
10/21/80	37	7.6	7.0	8.6	1.5	230	152				290	170	13.5	1.1	0.15
10/22/80	36	7.8	6.8	9.8	2.0						300		15.0	1.4	
10/24/80	37	7.5	6.6	8.2	1.8	210					290	215	20	1.2	5.9
10/25/80	37	7.7	7.3	6.8	2.6	212					215	165	8.8	1.6	2.0
10/28/80	39	7.8	6.7	5.5	3.1	208		250	160	90	270	172	8.8		2.3
10/29/80	39	7.4	6.7	5.4	2.9	230	194	260	146	114	310	180	11	1.6	0.55
11/4/80	37	7.4	6.8	7.0	2.1			256			220		9.8		
11/5/80	37	7.4	6.7	6.2	2.0	208		248	142	106	200	120	9.8	1.1	
11/10/80	37	7.9	6.9	7.0	1.8	238		280	158	122	325	210	13	1.1	

TABLE 2
ADDITIONAL SANGAMON RIVER ANALYSES

DATE	AMMONIA (mg/1 AS N)	FLUORIDE (mg/1)	FLUORIDE (mg/1)	TOTAL IRON (mg/1)	TOTAL IRON (mg/1)	FECAL COLIFORM (#/100 ml)		TOTAL COLIFORM (#/100 ml)		STD. PLATE COUNT		CHLORINE DIOXIDE (mg/1)	TOTAL CHLORINE (mg/1)	FREE CHLORINE (mg/1)	COLOR (UNITS)	COLOR (UNITS)
	RAW	RAW	TREATED	RAW	TREATED	RAW	TREATED	RAW	TREATED	RAW	TREATED	TREATED	TREATED	TREATED	RAW	TREATED
9/26/80						190	0					0				
10/1/80					0.2	50	4									
10/2/80						150	0					0.1				
10/3/80		0.72	0.42	0.18	0.02											
10/6/80				0.21	0.03							0.1				
10/9/80						170	0						0.5			
10/13/80								2,000	2				1.5			
10/14/80		0.96								17,000	6		1.5			
10/15/80						40	0									
10/16/80													2.0			
10/17/80	5.0	0.93	0.64	0.26									2.0			
10/21/80	9.7	0.96	0.70	0.25	0.07											
10/22/80				0.21	< 0.01	55	0	140	0	13,400	4			0.5		
10/24/80	7.6	0.89	0.52													
10/25/80	5.3	0.76	0.65													
10/28/80	1.6	0.78		0.1		500	2	2,600NON*	39NON*	7,500	990			0	25	< 5
10/29/80	6.1	1.06	0.78	0.15		40	8	0(14,200)	10(2,460)	3,300	1,670			0	50	< 5
11/4/80															25	< 5
11/5/80		0.77	0.56												25	< 5
11/10/80		0.87	0.62	0.31	0.03										40	< 5

* Atypical Colonies


LAKE SPRINGFIELD
DIVIDING DAM
PRE-TREATMENT COMPLEX
6 - 51.5' HFR CLARIFIERS
PUMPING STATION
2 - 38 MGD PUMPS
SOUTH FORK CHANNEL DAM
SANGAMON RIVER CHANNEL DAM
570
560
550
540
530
520
510
500
CHLORIDE DIOXIDE
100 Year Flood -548
100 Year Flood - 544
ACTIVATED CARBON
SLUDGE
CAT. POLYMER and/or METALLIC SALT
City of Springfield, Illinois
PRELIMINARY PROFILE
PROPOSED DIVERSION AND
PRE-TREATMENT FACILITIES

FLOW MGD	SURF. RISE GPM/FT²	RETENTION MIN
18	1.0	80
27	1.5	53
36	2.0	43
45	2.5	32
54	3.0	26
62	3.5	23

AT 100 Mg/L RAW WATER
SLUDGE 25,000# / DAY
250,000 GAL/DAY

Figure 1 Preliminary Profile

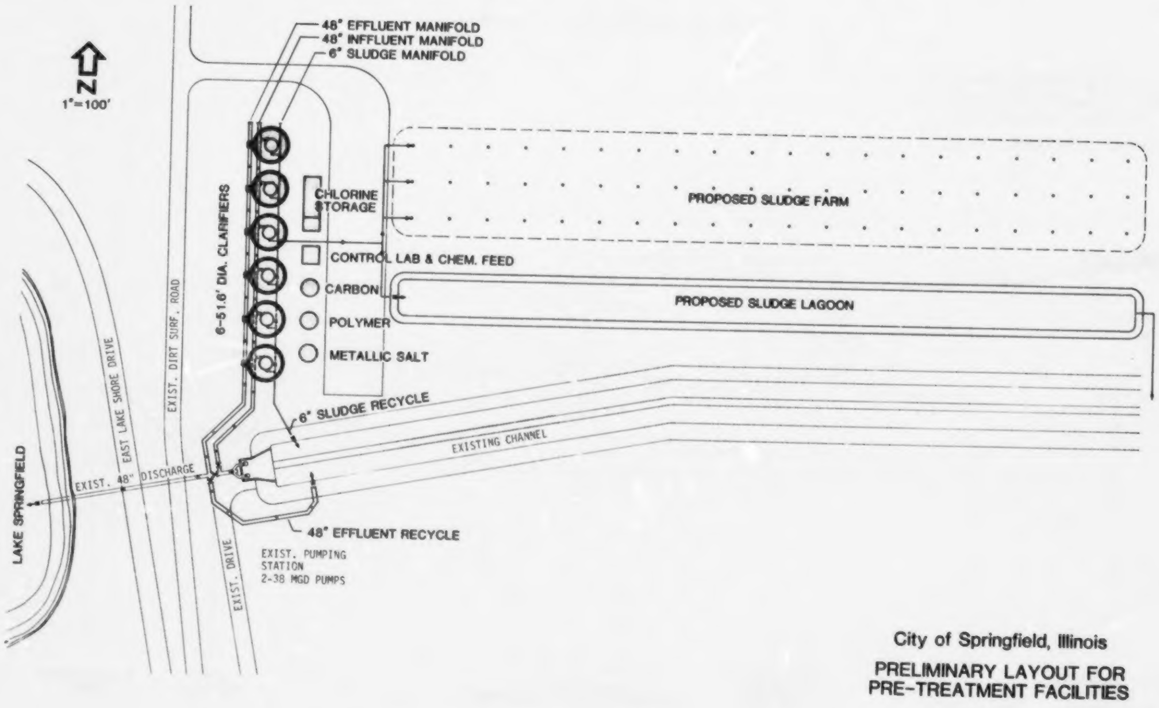
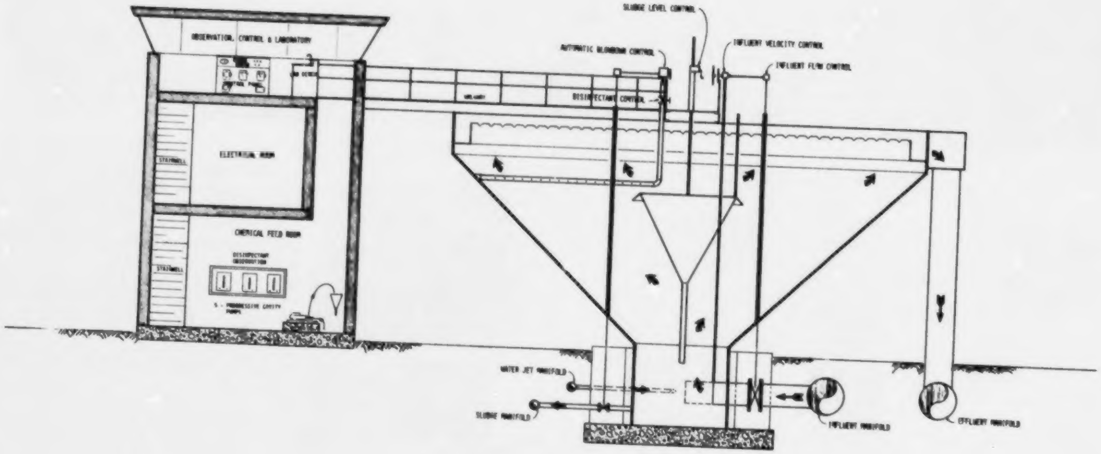

N
1"=100'
48" EFFLUENT MANIFOLD
48" INFFLUENT MANIFOLD
6" SLUDGE MANIFOLD
6-51.6' DIA. CLARIFIERS
CHLORINE STORAGE
CONTROL LAB & CHEM. FEED
CARBON
POLYMER
METALLIC SALT
PROPOSED SLUDGE FARM
PROPOSED SLUDGE LAGOON
6" SLUDGE RECYCLE
EXISTING CHANNEL
48" EFFLUENT RECYCLE
EXIST. PUMPING STATION 2-38 MGD PUMPS
EXIST. DRIVE
EXIST. DIRT SURF. ROAD
EAST LAKE SHORE DRIVE
EXIST. 48" DISCHARGE
LAKE SPRINGFIELD
City of Springfield, Illinois
PRELIMINARY LAYOUT FOR PRE-TREATMENT FACILITIES

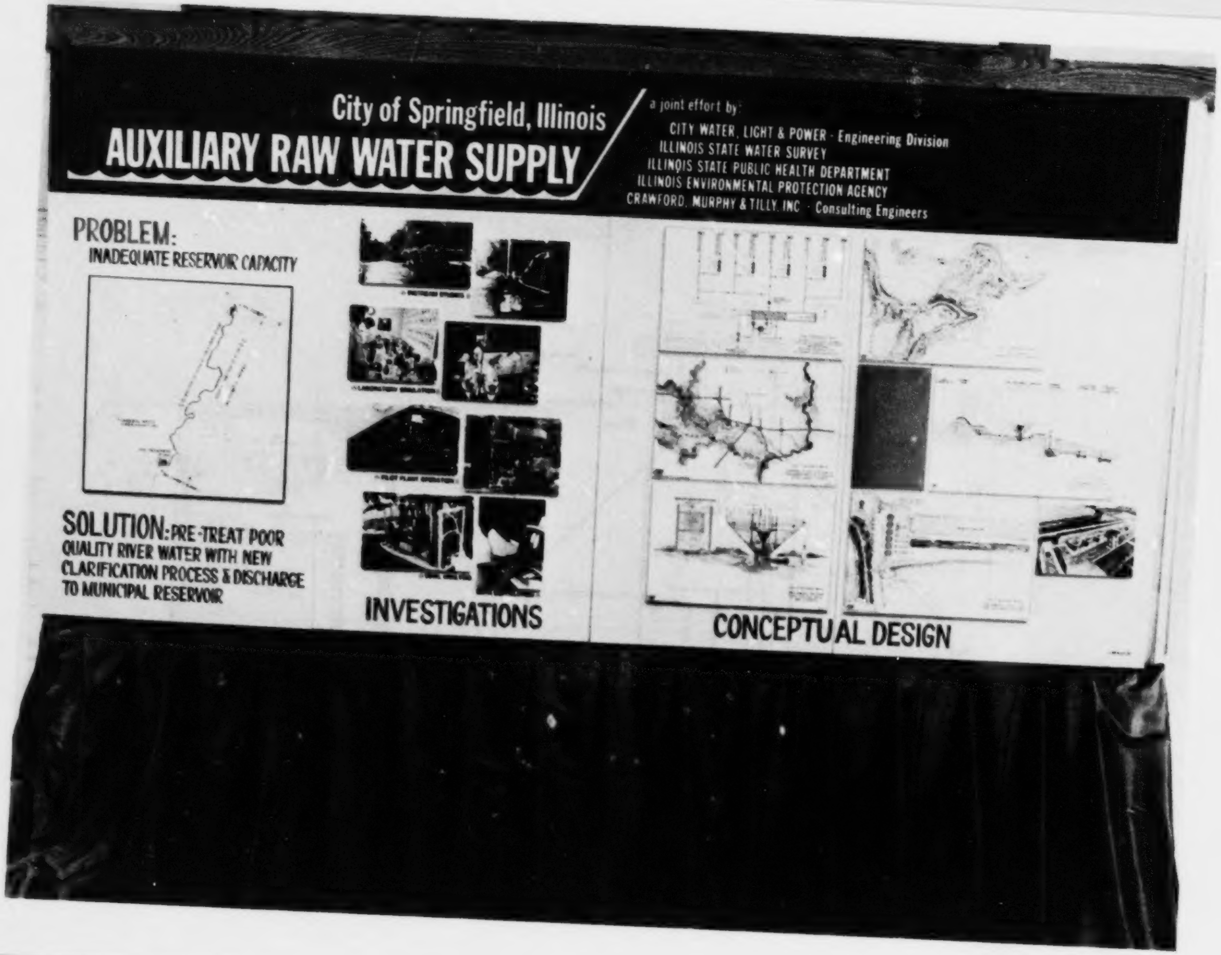
Figure 2 Preliminary Layout


OBSERVATION, CONTROL & LABORATORY
CONTROL PANEL
ELECTRICAL ROOM
STAIRWELL
CHEMICAL FEED ROOM
DISINFECTANT
STAIRWELL
5 - PROGRESSIVE CAVITY PUMPS
AUTOMATIC BLOWDOWN CONTROL
DISINFECTANT CONTROL
SLUDGE LEVEL CONTROL
INFLUENT VELOCITY CONTROL
INFLUENT FLOW CONTROL
WATER JET MANIFOLD
SLUDGE MANIFOLD
INFLUENT MANIFOLD
EFFLUENT MANIFOLD

City of Springfield, Illinois

PRELIMINARY SECTION
THRU CONTROL BLDG.
AND CLARIFIER

Figure 3 Preliminary Section



City of Springfield, Illinois

AUXILIARY RAW WATER SUPPLY

a joint effort by:

CITY WATER, LIGHT & POWER · Engineering Division
ILLINOIS STATE WATER SURVEY
ILLINOIS STATE PUBLIC HEALTH DEPARTMENT
ILLINOIS ENVIRONMENTAL PROTECTION AGENCY
CRAWFORD, MURPHY & TILLY, INC. · Consulting Engineers

PROBLEM:
INADEQUATE RESERVOIR CAPACITY

SOLUTION: PRE-TREAT POOR QUALITY RIVER WATER WITH NEW CLARIFICATION PROCESS & DISCHARGE TO MUNICIPAL RESERVOIR

INVESTIGATIONS

CONCEPTUAL DESIGN

PB82-223280

USE OF RECLAIMED WASTEWATER FOR LANDSCAPE IRRIGATION

by
Michael E. Warren
Project Manager
and
Gary J. Swanson
Project Manager
CH2M HILL
P.O. Box 22508
Denver, Colorado 80222

INTRODUCTION

As population growth continues to boom in the semiarid western states, the development of new sources of water becomes increasingly important. The major use of domestic water during summer months is for landscape irrigation, which can account for up to 85 percent of total potable water used on peak days.

One new source of water which has until now been largely ignored by many municipalities and water districts is reclaimed wastewater. Quality requirements for irrigation waters vary, depending on the use of the land under irrigation. As a rule, these requirements are much less stringent than quality requirements for potable waters. The lower quality requirements can often result in wastewater reclamation treatment costs that are less than potable water treatment costs from established water sources. The cost advantages associated with water reclamation are even greater when water is a scarce commodity; massive expenditures may be required to develop and deliver water from previously unused sources.

COLORADO WATER LAW

Water in Colorado is a valuable resource. Its ownership and use are governed by water laws developed over the last 100 years. Waters of Colorado are "appropriated" to those persons who first put the water to beneficial use. The availability of the water for successive beneficial uses (e.g., landscape irrigation) depends on the source of the water, historical precedents of others relying on no reuse of the water, and a myriad of other factors.

Prior to the development of water reclamation projects, the right to reclaim water must be established. Like many of the water-short western states, Colorado has very complex water laws. Colorado laws governing appropriation of rights vary according to the water source, and legal distinctions are made for tributary waters, nontributary ground waters, and out-of-basin transfers (imported waters).

Tributary water is defined as all surface water that naturally flows in or into the main stem of a stream system. All water in the shallow alluvium of the tributary streams is also considered tributary. Tributary water is subject to limits that prevent a user from causing injury to vested rights of others. Thus, reuse of wastewater originating from tributary surface or ground water will not be allowed if it increases the consumptive use beyond historically practiced consumption, or otherwise affects the quantity or quality of water available to any downstream user.

Nontributary ground water is water taken from deep aquifers which do not contribute to flow in any natural streams. Nontributary water is usually 100-percent available for reuse and/or successive use; however, in general, the quantities of water from these sources are insufficient to meet large demands.

In Colorado, imported waters are generally considered those diverted from streams west of the Continental Divide for use along the more densely populated Eastern Slope. Except in special circumstances, this water is 100-percent reusable. Currently, the major owners of imported water in Colorado are the Front Range cities of Aurora, Colorado Springs, Denver, Fort Collins, and Loveland.

In summary, most imported and nontributary waters are available for reuse, recycling, or successive use, whereas tributary water is subject to limits that prevent an appropriator from causing injury to the vested rights of others.

TREATMENT STANDARDS

The Colorado Department of Health is currently updating its requirements for use of reclaimed wastewater for landscape irrigation. Until now, the state has generally required an effluent quality of 30 milligrams per liter (mg/l) each for biochemical oxygen demand (BOD_5) and total suspended solids (TSS), with less than 200 fecal coliform organisms per 100 milliliters (ml). Since 1977, these standards have been used for reclaiming wastewater used to irrigate golf courses, cemetaries, and greenbelt areas.

With the increased pressures to reclaim additional wastewater for irrigation of industrial and commercial lawns and parks used for team sports (football, baseball, soccer, etc.), the state has indicated that additional standards will be issued. The additional standards are expected to be based in part on reuse standard established by the State of California.[1] Colorado has indicated that there will likely be three classifications used in the future. They are:

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[1] Title 22, Division IV, State Administrative Code, State of California.

Group I

Uses: Golf courses, cemetaries, freeway landscapes, and greenbelts

Discharge standards:

30 mg/l BOD[2]
30 mg/l TSS[2]
200 fecal coliform organisms/100 ml[3]
6 to 9 pH

Group II

Uses: Industrial and commerical lawns and parks where there is little or no full body contact with the irrigated soil (e.g., softball, baseball, volleyball, etc.)

Discharge standards:

30 mg/l BOD[2]
30 mg/l TSS[2]
23 total coliform organisms/100 ml[3]
6 to 9 pH

Group III

Uses: Irrigation of residential lawns and playgrounds or areas that may be used for body contact sports (e.g., football, rugby, wrestling, etc.)

Discharge standards:

20 mg/l BOD[2]
20 mg/l TSS[2]
2.2 total coliform organisms/100 ml[3]
2 NTU turbidity units[4]
6 to 9 pH

Monitoring requirements are expected to closely follow these examples:

Parameter	Frequency
Flow	Daily
BOD$_5$ and TSS	Weekly
pH, coliform, turbidity	Daily

---

[2] Monthly averages.

[3] Geometric average in any 7-day period.

[4] Seven-day average, two consecutive days' average not to exceed 5 NTUs.

COLORADO REUSE PROJECTS

The practice of reclaiming wastewater for use in landscape irrigation is becoming increasingly common. Examples of this type of wastewater reclamation in the metropolitan Denver area are seen at the City of Aurora, which has been reclaiming wastewater at its Sand Creek Wastewater Treatment Plant since 1970; the Inverness Industrial Park Water and Sanitation District, which has been reclaiming wastewater since 1975; and the Eastwood Estates mobile home subdivision, which has been reclaiming wastewater since 1979. These three reclamation systems are typical of the diverse methods commonly used for reclaiming wastewater for landscape irrigation.

Sand Creek Wastewater Reclamation Facility

The City of Aurora, Colorado, uses reclaimed domestic wastewater to irrigate its 120-acre Aurora Hills Golf Course. Since 1970, when the reuse treatment facility was added to the treatment plant, Aurora uses an average of 100 million gallons per year of reclaimed wastewater for irrigation. The water is pumped 4 miles from the treatment facility to an onsite nonpotable water reservoir. Pumps draw water from the reservoir for irrigating. Modifications to the treatment facilities are currently under construction to double the capacity of the treatment systems, thus enabling the City to irrigate three municipal parks near the golf course. Irrigation of the parks will require an additional 50 million gallons per year, and treatment requirements will increase if and when the new Colorado standards go into effect.

Treatment Process

A conventional secondary activated sludge treatment plant constructed in 1960 has been the source of water for the reuse facility. The plant was originally designed to treat 1 million gallons per day (mgd), and consists of conventional screening and grit removal followed by aeration and final clarification. Disinfection is achieved by adding chlorine solution to the final clarifier effluent immediately upstream from the contact basin. Effluent from the contact basin was piped to the onsite 0.5-million-gallon reservoir. From there, the effluent was either reused or discharged into the nearby stream. The reuse system pumped the water from the reservoir through multimedia pressure filters and a 4-mile, 14-inch-diameter pipeline and discharged the water into the golf course reservoir for repumping to the irrigation distribution system.

For increased use of reclaimed wastewater for urban landscape irrigation, the City is currently expanding and modifying its reuse facilities to double its filtration capacities. In addition, the plant's effluent standards are being increased. When reclaimed water was used exclusively for irrigation of the golf course, the standards required only a discharge limit of 30 mg/l each of BOD_5 and TSS and 200 fecal coliform organisms per 100 ml. However, with the proposed standards for reuse water applied to parks with body contact sports such as football and soccer, a higher degree of treatment will be required.

Process modifications were made during the expansion to meet the proposed standards, including the addition of a flow-paced jet disinfection system to replace the old chlorine solution system. The reuse water for the parks will be taken directly from the line which feeds the onsite reservoir, rather than from the reservoir, thus maximizing the chlorine residual available. In the filter complex, provisions are being made for the addition of a polymer-feed system to improve solids recovery in the pressure filters. An additional chlorine-feed system is being installed to allow for postchlorination of all reclaimed water. The 4-mile pipeline allows for an additional 80-minute contact time at peak pumping rates. Figure 1 illustrates the modified flow schematic.

Reuse Practice

Aurora generates an average of approximately 16 million gallons per day of wastewater, of which 70 percent is imported water. The City could, therefore, reuse approximately 11 mgd with their current water rights.

After secondary treatment, the irrigation water is pumped to a 6-million-gallon reservoir at the golf course for storage. The reservoir has been designed to blend into the golf course. The visual appearance of the golf course is improved, and the course becomes more difficult because the reservoir is a major water hazard on two of the holes.

The existing treatment system meets the current standards for irrigation of the golf course. With the modifications under way, the treatment facility will produce an improved water quality. Table 1 presents the water quality characteristics of the existing facility and the characteristics anticipated upon completion of the construction program.

Table 1
RECLAIMED WASTEWATER CHARACTERISTICS
SAND CREEK WASTEWATER RECLAMATION FACILITY

Characteristics	Existing Facility	Modified Facility (Estimated)	Units
BOD_5	7	5	mg/1
TSS	8	5	mg/1
TDS	550[a]	550	mg/1
NO_3-N	9	2	mg/1
NH_3-N	7	14	mg/1
pH	7.1-7.5	7.1-7.5	standard units
Fecal coliform	200	0	organisms/100 ml
Turbidity	4	2	NTU

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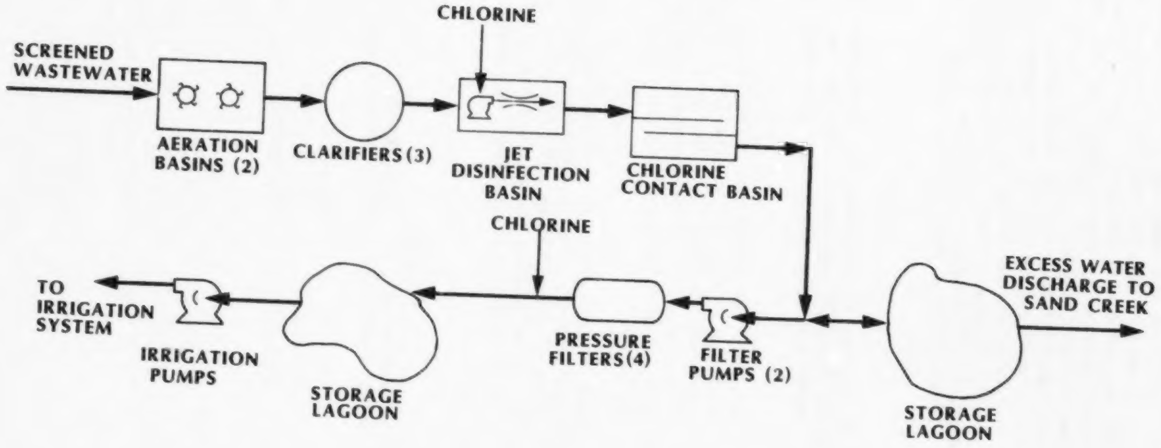
[a] Estimated


SCREENED WASTEWATER
AERATION BASINS (2)
CLARIFIERS (3)
CHLORINE
JET DISINFECTION BASIN
CHLORINE CONTACT BASIN
CHLORINE
EXCESS WATER DISCHARGE TO SAND CREEK
TO IRRIGATION SYSTEM
IRRIGATION PUMPS
STORAGE LAGOON
PRESSURE FILTERS(4)
FILTER PUMPS (2)
STORAGE LAGOON

AURORA SAND CREEK
PROCESS TRAIN

Figure 1

Three problems have been associated with the use of reclaimed water from this facility:

- Algal growths in the reservoir which contribute to unsightly conditions and some sprinkler nozzle-clogging
- Debris entering the piping system from the open reservoir which causes some nozzle-clogging
- Salt buildup in low-lying areas where ponding of surface runoff occurs

To alleviate problems with algal growths, algaecides are used on a continuing basis. To prevent debris from entering the piping system, a self-cleaning drum strainer was recommended for installation on the pump discharge. Salt buildup problems are mitigated by regrading to eliminate areas of ponding, or by seeding those low-lying areas with more salt-resistant strains of grasses.

Economics

The economics of the Sand Creek reuse program have been quite favorable for the City of Aurora. In the past, an average of 100 million gallons per year was used for irrigation. The 1980 costs of the reuse system, including debt service of the original filtration complex and transmission line, but excluding irrigation pumping costs, averaged $0.43 per thousand gallons.

The savings to the City, based on a use of 100 million gallons per year in 1980, was $55,000. With the increase in treatment requirements, the expanded treatment system modifications, additional 2 miles of transmission line and an irrigation pump station, the 1983 reuse costs will be approximately $0.78 per thousand gallons, which still represents a cost savings of $0.25 per thousand gallons when compared to current potable water costs. The estimated 1983 cost includes amortized capital costs (30 years at 12 percent) and operation costs for treatment, transmission, and final pumping to the irrigation distribution system.

Future Plans

The City plans to expand the reuse system to include three parks in 1982. At that time, extension of the reuse system to other parks and golf courses will be considered. It appears that the City intends to increase its reuse system to conserve as much potable water as possible for domestic use.

Inverness Water and Sanitation District

Since 1975, the Inverness Water and Sanitation District has utilized reclaimed wastewater from the commercial office park it services for irrigation of the park's 18-hole, 140-acre golf course. The Inverness Office Park, located south of Denver will ultimately have over 1,000 acres developed with a projected average daily wastewater flow of 0.9 mgd. The development is recording flows of 150,000 gallons per day (gpd); that amount is expected to double by the summer of 1985. All wastewater flows are collected and treated at the

District's treatment facility. The treated effluent is pumped to an onsite reservoir for storage and is later used to irrigate the golf course. The golf course uses an average of 100 million gallons of water per year; almost half this amount is reclaimed wastewater.

Treatment Process

The District's packaged activated sludge treatment plant was originally rated at a capacity of 150,000 gpd. However, because of the nature of the wastewater flow at the office park, nearly 70 percent of the flow is received during the 10-hour period from 7:30 a.m. to 5:30 p.m. For this reason, a flow equalization basin is currently being constructed at the treatment facility. When the flow equalization basin is completed, the treatment facility is expected to be capable of treating an average flow of 200,000 gpd.

When construction is completed, the facility will include a flow equalization basin, aeration basins, secondary clarifier, and a chlorine contact basin. Disinfection of the wastewater is accomplished using chlorine gas put into solution which is mixed with the secondary effluent. At a flow rate of 200,000 gpd, a theoretical contact time of 60 minutes is provided.

Reuse Practice

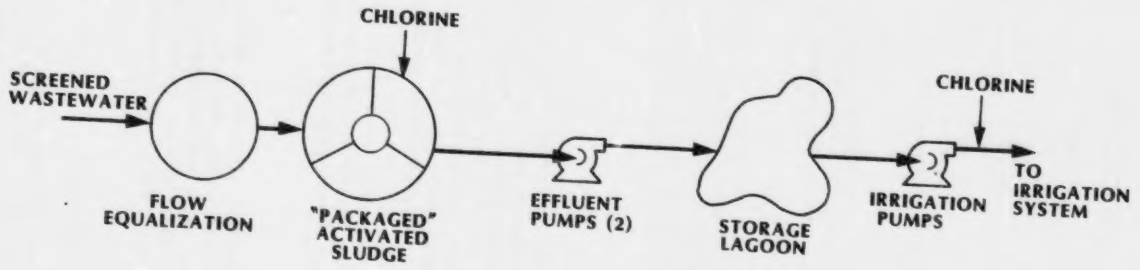
Since the domestic water used in the District comes from deep aquifers considered nontributary to any surface streams, all of the water can be reused.

The treatment facility's chlorinated effluent is pumped through 4,200-foot-long, 8- and 10-inch pipelines to a storage reservoir, allowing an additional contact time of 20 minutes. The treatment and reuse system is shown on Figure 2. The storage reservoir, which is not part of the golf course, has a capacity of approximately 55 million gallons. The reservoir is designed for an annual fill and draw; the water fluctuation is approximately 20 feet. The reservoir receives all water from the wastewater treatment plant; thus, it is sized to store water throughout the year, with irrigation occurring from April through October.

The average application of water to the golf course is equivalent to 0.55 mgd, with peaks of 1.4 mgd. Of the 100 million gallons required to operate the irrigation system annually, the current wastewater flow provides approximately 40 percent, with the remaining 60 percent provided by the District's wells. Based upon current projections, 100 percent of the irrigation demands will be met with reclaimed wastewater by 1985.

The irrigation pump station which draws water from the storage reservoir is capable of adding chlorine to the irrigation water prior to its being pumped to the distribution system. However, in general, the addition of chlorine is not required to meet the discharge standard of 200 fecal coliform organisms/100 ml.

The typical water quality of the irrigation water discharged to the storage reservoir is presented in Table 2.


SCREENED WASTEWATER
FLOW EQUALIZATION
CHLORINE
"PACKAGED" ACTIVATED SLUDGE
EFFLUENT PUMPS (2)
STORAGE LAGOON
CHLORINE
IRRIGATION PUMPS
TO IRRIGATION SYSTEM

INVERNESS
WATER AND SANITATION DISTRICT
PROCESS TRAIN

Figure 2

Table 2
TYPICAL RECLAIMED WASTEWATER CHARACTERISTICS
INVERNESS WATER AND SANITATION DISTRICT

Characteristics	Concentration
BOD_5	20 mg/l
TSS	20 mg/l
TDS	460 mg/l
NH_3-N	14 mg/l
Na	20 mg/l
SO_4	30 mg/l
pH	6.9-7.3
Fecal coliform	20 organisms/100 ml

Water quality at the sprinklers will generally be equal to that shown in Table 2, with the exception of TSS and fecal coliform; these values may be markedly higher due to the presence of algal blooms and waterfowl on the reservoir.

Based upon discussions with the operation personnel, the only major difficulty experienced is occasional nozzle-plugging of the sprinkler heads due to material being pumped from the uncovered storage reservoir. The recommended minimum size nozzle opening is 3/16 inch. A 1/4-inch nozzle is preferred if the site conditions permit use of rotary sprinklers.

Economics

The 1980 costs of the reuse system, excluding debt service but including all operation and maintenance costs of the reuse pumping systems, averaged $0.64 per thousand gallons. Because of the high cost of obtaining additional water for irrigation, which is estimated at over $1.00 per thousand gallons, the District is saving over $0.36 per thousand gallons of water used. As the District grows and a greater percentage of the irrigation water demand is met with reclaimed wastewater, the District will realize greater savings. The 1980 operation and maintenance costs include the costs associated with the treatment plant pumping system, storage facility maintenance, and the distribution system pumping facility.

Future Plans

Future plans for the District include irrigation of the lawns and open space areas. Plans are already under way for a complete dual distribution system. Use of the reclaimed wastewater for lawn irrigation will require additional treatment to meet the stringent water quality standards proposed by the Colorado Department of Health.

Eastwood Estates Mobile Home Subdivision

In 1979, the Eastwood Estates mobile home subdivision, located north of Denver in Adams County, began operation of a system to reclaim and reuse all the wastewater generated in the 220-acre development. Eastwood Estates is a true mobile home subdivision in which all occupants own their lots and mobile home units. Included in the initial development plan was a 19-acre greenbelt area surrounding First Creek, a small stream which bisects the area. Until the reclaimed wastewater became available, no attempts were ever made to develop the greenbelt because of the high water demands required to establish growth in the sandy alluvial soils. With 18 million gallons per year of reclaimed water now available, the areas currently under irrigation have started to establish good growths of native grasses, and an attractive recreational area can be developed in the near future.

Treatment Process

The treatment facility as shown on Figure 3 consists of a lagoon system sized for storage of 6 months' flow. Wastewater is pumped into an aerated cell, where two 15-horsepower (hp) floating aerators mix and oxygenate the wastewater. After approximately 20 days under aeration, the wastewater flows into three settling/storage lagoons. The lagoon piping is arranged to allow routing of the flow through all lagoons in series or in parallel, or to bypass any lagoon without operational interference.

After storage, the water is pumped from the lagoons; chlorine solution is injected into the pump discharge lines for disinfection. The chlorinated water then passes into a pressurized chlorine contactor (a 200-foot length of 48-inch diameter steel pipe with baffles), which provides 30 minutes of contact time at peak flow conditions. The chlorine contactor has bottom blowoff pipes to allow for removal of accumulated algae sediments during operation. Algae control can also be attempted by returning chlorine solution to the storage lagoons.

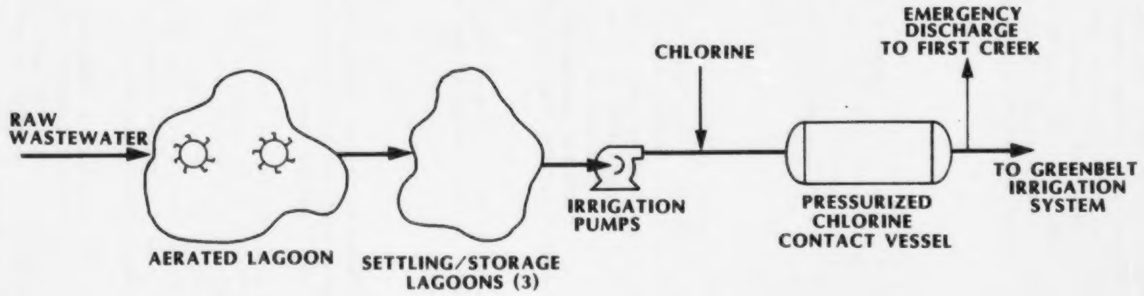
The system was sized to treat an average daily flow of 165,000 gpd, which is sufficient to meet all the treatment needs of the entire development.

Reuse Practice

All of the domestic water used at Eastwood Estates comes from four deep-aquifer wells. Since these deep aquifers are not tributary to any surface streams, all the wastewater can be reused.

The irrigated area is immediately adjacent to the storage lagoons, thus reducing distribution costs for the first phase of the irrigation system installation. Electrically controlled zone valves are timed to irrigate the greenbelt from 10 p.m. to 4 a.m., when the area is closed to public use. Although most irrigation takes place from April through October, some winter irrigation is practiced if temperatures are warm and soil moisture levels are low.

The irrigation system is set up to use reclaimed wastewater only; there is no provision for makeup of extra water demands from other sources. To account for expected growth in the development and to ensure that sufficient water is available to maintain growth throughout the summer months, the irrigation system is being installed in phases. The amount of land under irrigation is matched to the


RAW
WASTEWATER
AERATED LAGOON
SETTLING/STORAGE
LAGOONS (3)
IRRIGATION
PUMPS
CHLORINE
PRESSURIZED
CHLORINE
CONTACT VESSEL
EMERGENCY
DISCHARGE
TO FIRST CREEK
TO GREENBELT
IRRIGATION
SYSTEM

EASTWOOD ESTATES
PROCESS TRAIN

Figure 3

projected wastewater flow from developed areas so that the danger of exhausting the irrigation water supply is minimized.

Water quality from the storage lagoons is highly variable, depending on algal growths, the algal control measure used, the degree of algal settling experienced in the chlorine contactor, etc. The variation is so great that "average" quality data are not meaningful. Despite this variation in effluent quality, plugging problems in the sprinkler system have been minimal. The impact spray heads have 1/4-inch nozzles which seem to be resistant to plugging. The zone valves have screens over the operator orifices which have been inspected yearly and show no signs of clogging due to algae or slime growths.

The major problems encountered in the reuse system have related to vandalism. Since the irrigation system was installed in a loose, sandy alluvium soil, the owner requested that pop-up heads not be used. The spray heads were mounted on galvanized steel pipe risers 2 inches in diameter, with an 18-inch diameter concrete mowing pad around each riser. The below-grade connection between the riser and the lateral was made with flexible PVC to allow for some settlement and shifting. Despite these efforts, vandalism damage has been severe, including stolen heads, broken heads, and smashed valve boxes. Several risers were destroyed by a vehicle driven through the greenbelt. At present, no solution has been found for the vandalism problem; no system which exposes components to view will be entirely satisfactory in this area.

Economics

The cost of reclaiming wastewater was only one of the economic factors which led to the decision to reuse domestic wastewater at Eastwood Estates. Additional concerns included:

- The potable wells did not have sufficient capacity to meet domestic and greenbelt irrigation requirements, thus necessitating a new water source to meet the commitments of the development plan.
- The county planning department had placed a building moratorium on the development pending improvement of the wastewater treatment system. A "zero discharge" reuse system was easier to implement than a system discharging to the stream.

The estimated 1980 cost of reclaiming wastewater for irrigation purposes was $1.09 per thousand gallons. This includes $0.36 per thousand gallons for operation and maintenance and $0.73 per thousand gallons for debt retirement. These costs are for the water storage reservoir, disinfection system, and irrigation pump system.

Future Plans

Future plans include expansion of the irrigation system with the growth of the development. A major water supply line from Denver has just been completed, and it is expected that a major collection interceptor will soon be extended past the development. At that time, the developer will be offered the options of locating a new source of irrigation water and abandoning the reuse system, or continuing in the present manner.

SUMMARY

Wastewater reclamation for landscape irrigation is a viable option for many growing communities desiring to reduce ever-increasing demands for potable water. Suggested standards for landscape irrigation water in Colorado vary, depending upon the uses proposed for the irrigated land.

Water rights questions in Colorado represent complicating factors in establishing the legal right to reuse water. In general, however, water which is transferred from its original watershed basin (i.e., imported water) and water from deep, nontributary aquifers is usually available for reuse.

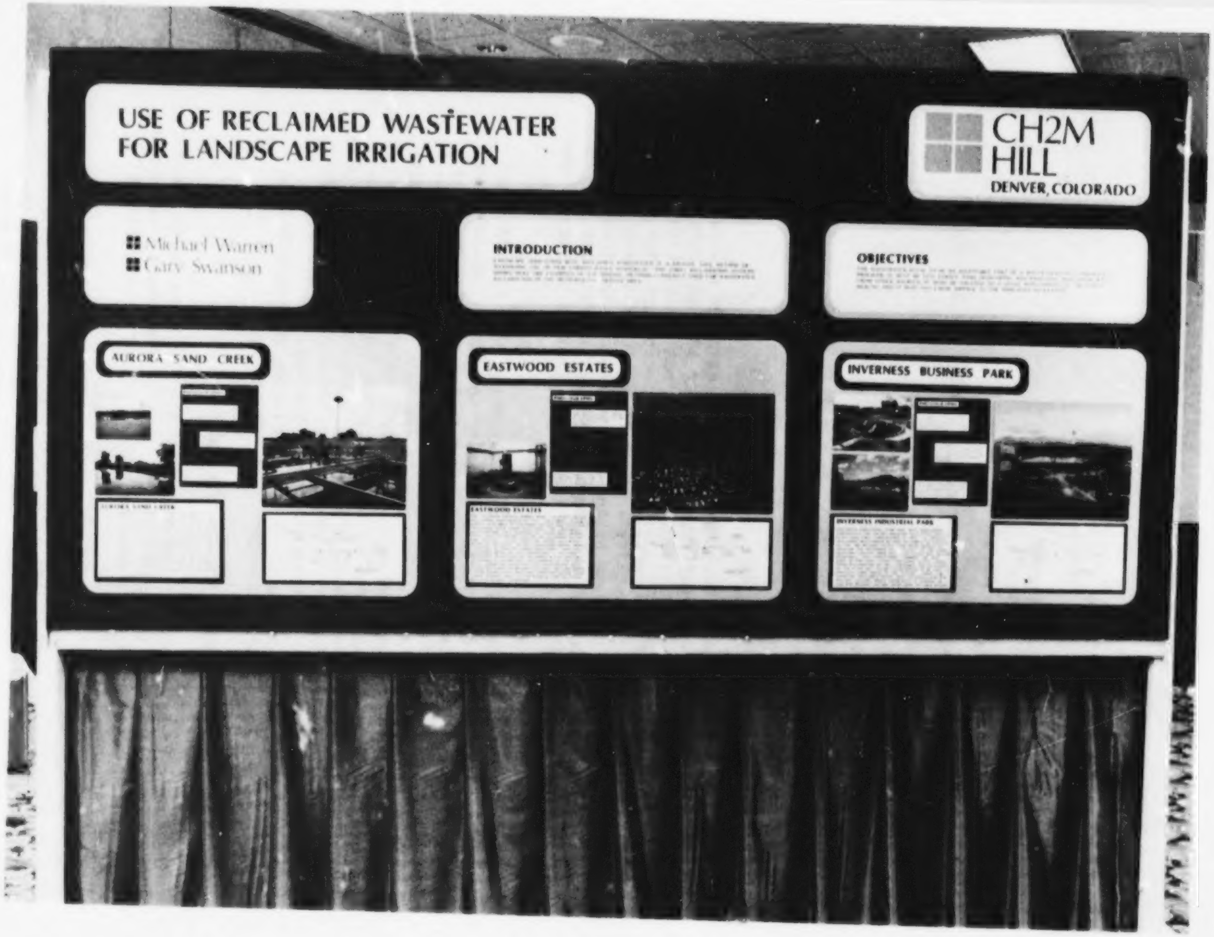
The Sand Creek reclamation system provides an example of water which will be treated to a relatively high degree and reused in a variety of ways. Past practice has been to irrigate only golf courses with the water, while future plans include irrigation of golf courses and multiple-use public parks which require the highest level of reclamation treatment. Costs for this level of treatment range from $0.43 per thousand gallons to $0.78 per thousand gallons. Problems encountered with this system have related to algal blooms in the storage reservoir, debris plugging the nozzles, and salt buildup in low-lying areas.

The Inverness Industrial Park reclamation system provides an example of an intermediate treatment system. Reclaimed wastewater from Inverness is used to irrigate a golf course and in the future may be used to irrigate lawns in the industrial park. Costs for treatment at Inverness average $0.64 per thousand gallons. The only problem encountered with this system is plugging of the nozzles.

The Eastwood Estates reclamation system provides an example of a low-level treatment system used for greenbelt irrigation only. Factors other than costs were the prime motivators in selecting reuse of wastewater at Eastwood Estates. Costs at Eastwood Estates average $1.00 per thousand gallons for this small system. Most of the problems with this system occur because of vandalism to the the spray heads.

In all of these systems, public acceptance has been excellent. The areas are posted as irrigated with reclaimed wastewater, and no negative reactions have been expressed by users of the irrigated facilities.

Landscape irrigation with reclaimed wastewater is a proven, safe method of stretching limited water supplies in the water-short western states. As population growth continues, many other areas of the country may face the water shortage problems which the western states have dealt with for many years. A water reuse program, properly planned to meet the unique needs of the community, can be an important part of the overall program to maximize use of our limited water resources.



USE OF RECLAIMED WASTEWATER FOR LANDSCAPE IRRIGATION

CH2M HILL
DENVER, COLORADO

Michael Warren
Gary Swanson

INTRODUCTION

OBJECTIVES

AURORA SAND CREEK

EASTWOOD ESTATES

INVERNESS BUSINESS PARK

INVERNESS INDUSTRIAL PARK

PB82-223298

USE OF INFILTRATION/PERCOLATION BEDS TO PRODUCE A HIGH QUALITY RENOVATED WATER IN COLD CLIMATE REGIONS

Gordon W. Bruchner
Vice President

Timothy J. Carlson
Senior Engineer
ARIX, A Professional Corporation
760 Horizon Drive
Grand Junction, Colorado 81501

Mark L. Epstein
Environmental Specialist
ARIX, A Professional Corporation
2021 Clubhouse Drive
Greeley, Colorado 80631

INTRODUCTION

This paper presents the performance data of an advanced wastewater treatment pilot plant operated between September 1980 and July 1981 for Laramie, Wyoming. The goal of the project was to identify if aerated lagoon treatment followed by infiltration/percolation (I/P) beds could produce a high quality water suitable for discharge to the Laramie River and/or for reuse by the City. Reuse of the treated wastewater was given serious consideration after several years of limited raw water supplies and the lack of inexpensive sources of new water.

In December 1979 the facilities planning portion of a 201 EPA grant was completed for the City of Laramie. The selected alternative was to continue with aerated lagoon treatment followed by I/P beds and discharge to the Laramie River. Because little information is available on the operation and performance of I/P beds at high altitudes (7200 feet, 2195 meters) and during extremely cold winter months (-40°C is common for extended periods), a pilot I/P plant was constructed to verify operational parameters. Data from this pilot plant was used to develop the soil response relationships between hydraulic loading and wastewater solids and organic loading. Additionally, the results of 10 months of operation have indicated the potential for reuse of the renovated wastewater.

RELATIONSHIP BETWEEN WATER ORIGIN AND REUSE

The origin of water and its use are extremely important in the arid west with respect to the potential for reuse of the treated wastewater. In Wyoming water rights are governed by the "Prior Appropriations" doctrine which basically says:

1. The City is obligated to maintain historic return flows to the Laramie River attributable to all surface waters. Essentially, this means that the City does not have the right to reuse treated wastewater whose origin is from the Laramie River.

2. Laramie has the right to reuse or otherwise dispose of its effluent to the extent that the effluent is attributable to water derived from groundwater rights if such waters can be classified as "imported" waters to the Laramie River. Imported water is water which would not contribute to the flow of the Laramie River but for the diversion and use of such water by the City of Laramie.

For Laramie, which derives its water supply from both the Laramie River and wells located in a confined aquifer, the City should be able to reuse a portion of its treated effluent so long as water consumption does not exceed the developed water component (groundwater) of the domestic water supply. That amount available for reuse is no less than 2790 acre-feet/year ($3.4 \times 10^6 M^3$/year) between now and year 2000 (see Figure 1). The value of this water as a municipal water right is estimated to be worth approximately $1,500,000. The ability of the City to reuse this quantity of water will not only save them the cost of acquiring new water rights, but will also save in the cost of treatment if reuse water replaces potable water.

Three basic concepts for reusing treated wastewater are presented in Figure 2 and identified below.

Option A

The City would irrigate the golf course, cemetery, several small parks, and the University of Wyoming athletic complex with reuse water. Water quality criteria would be Biochemical Oxygen Demand (BOD_5) @ 10 mg/l, Total Suspended Solids (TSS) @ 10 mg/l, and Fecal Coliform @ 2/100 ml.

Option B

To provide a new drinking water supply, the City could exchange treated wastewater discharged to the river for an equivalent amount of river water taken upstream of the wastewater discharge. River water would receive basic water treatment and be pumped into the City's water distribution system. Water quality standards for discharge to the Laramie River are BOD_5 @ 30 mg/l, TSS @ 30 mg/l, Fecal Coliform @ 1200/100 ml, and Ammonia-N @ 0.9 mg/l.

Option C

Because flows in the Laramie River are extremely low during the summer months, it has been suggested that treated wastewater be pumped approximately 3 miles (4.8 kilometers) upstream to augment river flow and support a fishery during low flow periods. This concept also serves as the first step in developing a river park system. Reuse for in-City wildlife enhancement has the same water quality standards as Option B.

All three of these options would be implemented during the non-winter months only, the period when reuse water is most needed. The remainder of this paper addresses whether or not an aerated lagoon system followed by I/P beds can consistently produce a quality of water suitable for the aforementioned wastewater reuse options.

THEORY OF TREATMENT BY INFILTRATION/PERCOLATION BEDS

As partially treated wastewater passes through a soil mantle, numerous physical, biological, and chemical processes are occurring which remove many of the harmful constituents. These processes are noted with respect to the individual constituents which pertain to the reuse options.

The biochemical oxygen demand (BOD) may be thought of as the organic strength of wastewater. This strength is a function of the amount of chemical and biological materials that are easily oxidized. BOD is removed from water primarily by the action of aerobic soil bacteria that utilize these materials as nutrient sources. Also, BOD may be removed by the physical filtering action of the soil medium.

Total suspended solids (TSS) in the effluent from a lagoon system are principally some form of algae. TSS are primarily removed through the physical filtering action of the soil mantle. When allowed to dry, these solids generally biodegrade and are removed from the soil by environmental factors such as wind and rain in subsequent wastewater applications.

Fecal coliform are removed from wastewater by a number of different processes. These factors include filtering, drying, solar ultraviolet radiation, predation by other bacteria, and hostile environmental factors such as cold and hot temperatures.

Theoretically, ammonia would be removed from water applied to the I/P beds through various complex physical, chemical and biological reactions. During warmer spring, summer, and fall months, biological activities within the soil would be at a maximum. Certain bacteria within the soil are capable of converting ammonia into the oxidized form of nitrites (NO_2) and nitrates (NO_3). These bacteria are appropriately termed nitrifying bacteria and require oxygen to perform the conversion.

During the cold winter months, the bacteria that perform these conversions become inactive. Hence, in order to remove ammonia, non-biological processes must be utilized. Most soils have the capacity to adsorb a certain amount of positive ions (cations). This adsorptive capacity is termed the cation exchange capacity of the soil and is dependent primarily upon the amount and type of clay minerals present in the soil. Ammonia is categorized as a cation and, as such, is capable of being adsorbed onto the surfaces of some clay minerals. Thus, it is theoretically possible to remove ammonia from wastewater through non-biological activities during the colder winter months.

At the end of the cold period, the dormant nitrifying bacteria reactivate and can once again convert ammonia to nitrites and nitrates. The bacteria, in fact, can utilize that ammonia which was adsorbed onto the soil particles. This process restores the adsorptive capacity of the soil by replacing ammonia with hydrogen on the surface of the clay minerals. Thus, the ammonia applied through the winter months is treated and converted into the more desirable nitrites and nitrates once warmer temperatures are achieved.

DESCRIPTION OF I/P PILOT PLANT

Laramie's pilot I/P system was designed to test the ability of native soils adjacent to the existing treatment plant site to treat lagoon effluent for BOD, TSS, Fecal Coliform and Ammonia removal. NPDES permit limits for BOD and TSS are 30 mg/l, Fecal Coliform is 1200/100 ml during the period May 1 through September 30 (during the remainder of the year there is no limit on Fecal Coliform), and Ammonia-N limits are 0.9 mg/l (May 1 through September 30) and 2.3 mg/l (October 1 through April 30). Water quality standards for reuse are the same except for municipal irrigation in which BOD_5 is 10 mg/l, TSS is 10 mg/l, and Fecal Coliform is 2/100 ml. The basis of design was to use those desirable features found at other installations and to allow testing of the beds at various application rates and at various depths in the soil profiles.

Plan and section views of the Laramie pilot I/P system are presented in Figure 3. Two beds were constructed of native alluvial sands and gravels. A detailed soil analysis was conducted on the material used to fill the beds. The particle size analysis indicated that the material ranged in size from 98 to 99 percent sand and gravel with only 1 to 2 percent clay. Influent to the I/P system is drawn from the fourth cell of Laramie's existing lagoon system and then passes through 3 to 8 feet (0.9 to 2.4 meters) of unsaturated soils in the I/P beds.

The surface of the basins was formed into a ridge and furrow system. It was anticipated that the ridge and furrow approach would accomplish several goals. First, the ridge and furrow system would help minimize clogging in order to maintain rapid infiltration rates by directing the suspended solids to settle in the furrows and allowing the effluent to infiltrate through the sides of the ridges. Second, during winter months, it was anticipated that the ridges would help to support ice bridges. These ice bridges would insulate the furrows and assist in the maintenance of relatively high infiltration.

For the purpose of this study, it was decided to operate the beds at a loading rate of 3.5 feet (1.07 meters) per week or 130,000 gallons (492 m^3) per week for the two 2500 $ft.^2$ (0.02 ha) beds. This equates to 5% of the clear water infiltration rate. Dosage of the beds was arbitrarily set at Monday and Friday for the north bed and Monday, Wednesday, and Friday for the south bed.

RESULTS

During ten months of operation of Laramie's I/P pilot plant, significant amounts of data on a large number of parameters have been developed. This information is much too voluminous for this short text and is, therefore, summarized only. Graphs for the effluent from the I/P system for BOD, TSS, Fecal Coliform, and Ammonia-N are presented in Figures 4 through 7, respectively.

Biochemical Oxygen Demand (BOD)

BOD in the influent to the I/P beds averaged 32 mg/l and ranged between 24 and 72 mg/l. Removal efficiency through the I/P beds was a function of depth with BOD removal ranging from 21 percent for the shallowest drain to 99 percent for the deepest. Overall, the system performed as expected with effluent BOD concentrations averaging less than 7 mg/l from the lowest drain.

Total Suspended Solids (TSS)

Unlike BOD, it does not appear that TSS removal efficiency improved discernibly with depth. As would be expected, most of the suspended solids were removed on the basin's surface and upper layers of the soil profile. Although TSS influent concentrations ranged as high as 125 mg/l, effluent values from the I/P system were consistently below 5 mg/l.

Fecal Coliform

Similar to the removal of BOD, Fecal Coliform concentrations decreased with an increase in depth of treatment. Although the effluent concentration for Fecal Coliform from all drains was consistently good, the deeper drains were much less erratic in their removal rates. While the geometric mean of the influent was 2450/100 ml, the geometric mean for the lower drain was 55/100 ml and ranged only between 10 and 610 mg/l.

Ammonia-N

One of the primary functions of the Laramie I/P pilot study was to identify the Ammonia-N removal efficiencies that an I/P system could offer. As was expected, the greater the depth of unsaturated soil, the higher the removal efficiency with all drains at a depth of five feet (1.5 meters) or greater having Ammonia-N concentrations of less than 0.5 mg/l. This value is considerably below the summer NPDES limit of 0.9 mg/l and the winter limit of 2.3 mg/l. As winter set in, however, the removal efficiency decreased until mid-February when removal efficiency started an upward trend. Although the plant was still producing effluent Ammonia-N below the NPDES limit through the second week in January, the removal rates decreased dramatically after this point.

Decreases in Ammonia-N removal rates were attributed to two factors. One, the decrease in soil and water temperature during the winter caused the nitrifying bacteria to become inactive and thus they were unable to oxidize ammonia to nitrite and nitrate. Second, the soil characteristics of the I/P beds were dominated by coarse sands and gravels with only one to two percent clay and silt. This lack of fines resulted in a soil having only 1.2 milliequivalents/100 grams of soil of cation exchange capacity. To adequately adsorb Ammonia-N during the winter months, the soil should have a cation exchange capacity of 5 milliequivalents/100 grams of soil, or greater.

Other Wastewater Constituents

Besides the basic parameters which were tested, additional parameters were tested on a monthly basis. In general, as the wastewater passed through the soil, there was a slight increase in dissolved solids, principally in the form of calcium, magnesium, sodium, potassium, and sulfate. As would be expected, hardness and conductivity increased in about the same proportions. Since for every mg/l of Ammonia-N oxidized to nitrate-N, 7.14 mg/l of alkalinity is destroyed, bicarbonate and alkalinity concentrations normally decreased as Ammonia-N concentrations decreased. Volatile solids, a measure of organic material, decreased also as the wastewater passed through the soil -- a further indication of good BOD and TSS removal. Phosphate, which is removed by soil adsorption and some chemical precipitation, had approximately 75 percent removal initially, but decreased to 10 percent by the fourth month, thus indicating few adsorption sites available in the predominantly sand/gravel soil.

Physical Operation

Although the winter of 1980-81 was mild for Laramie (averaging several degrees above normal), there were several occasions when severe weather tested the I/P pilot plant. In both December and January there were several weeks in which the night-time temperatures regularly dropped below -10°F (-23.5°C) and never rose about 15°F (-9.5°C) during the day. During these weeks, no problems were encountered with the operation of the I/P beds.

As was theorized, the use of ridge and furrows caused the formation of ice bridges. These ice bridges helped to insulate the beds and thus kept them from freezing. Some ice bridges collapsed, but were subsequently floated or melted with the next application of wastewater. The major problem encountered with the ice bridges was the formation of a partial vacuum under the ice which would not allow the wastewater to percolate. The solution was simply to poke holes in the ice to allow air to enter. Another solution is to construct several rock mounds in the basins which allow air to enter below the ice.

The other reason for constructing ridge and furrows was to attempt to deposit the suspended solids material in the troughs and leave the sides of the ridges relatively clear for infiltration. This appeared to be exactly how the system functioned.

At all times during the operation of the I/P beds, there was never a point at which the system even approached discontinuation because of freezing. This, in spite of the fact that the applied wastewater was consistently at 32°F (0°C) to 34°F (1°C).

Operation of the dosage sequence did, however, affect infiltration rates. Every other day dosage of the south bed caused a noticeable reduction in infiltration rates, whereas the north bed dosed at a semi-weekly rate did not have a noticeable decline in infiltration. This was attributed to a longer drying and decomposition interval for the north bed.

CONCLUSION

With regard to BOD, TSS and Fecal Coliform, the performance of the I/P pilot study was excellent. Effluent quality was far superior to that required by Laramie's NPDES permit. Operation of the facility during the winter months proved the theory of the ridge and furrow approach to be a viable operational scheme. Ammonia-N removal was excellent until the colder soil and water conditions caused the nitrifying bacteria to become inactive. A solution to this problem is to provide more cation exchange capacity or to provide winter storage.

The reuse of I/P bed effluent for municipal irrigation will require the addition of a chlorination facility to decrease the Fecal Coliform concentration below 2/100 ml. However, since TSS and Fecal Coliform values already tend to be low in the I/P effluent, chlorine demand should not be significant. Both of the other reuse options can use the I/P bed effluent without further treatment during the non-winter months. If a need existed for winter reuse water, only Ammonia-N would be a limiting constituent.

ACKNOWLEDGEMENTS

Appreciation is extended to the following individuals who have helped during the I/P pilot plant project: Bruce Jones - wastewater plant operator for the City of Laramie, Jim Nelson - Laramie City Engineer. Gordon Bruchner, Tim Carlson, and Mark Epstein are employed by ARIX, P.C., an AE firm with offices in Colorado, Utah and Wyoming.

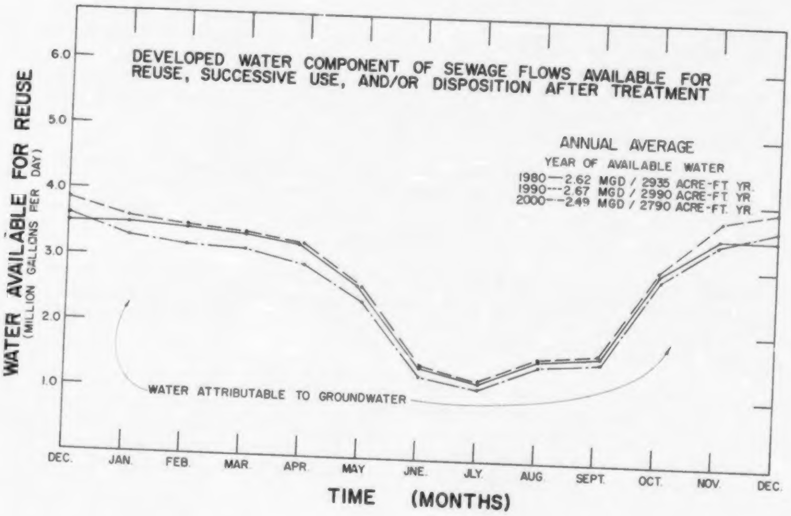


Figure 1

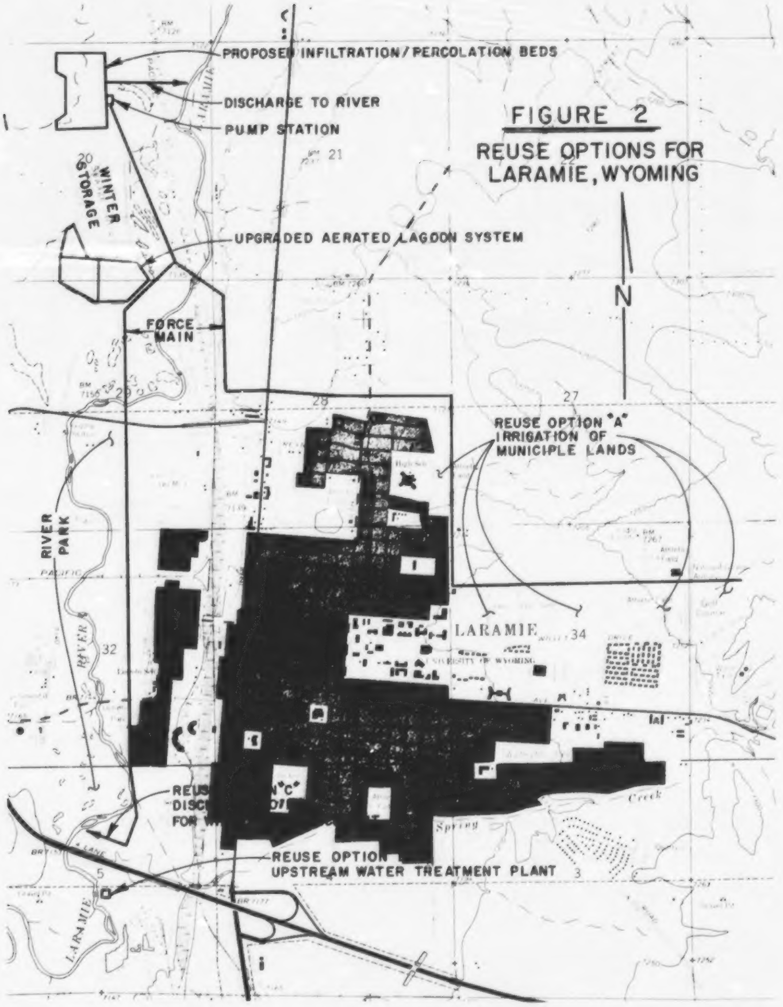
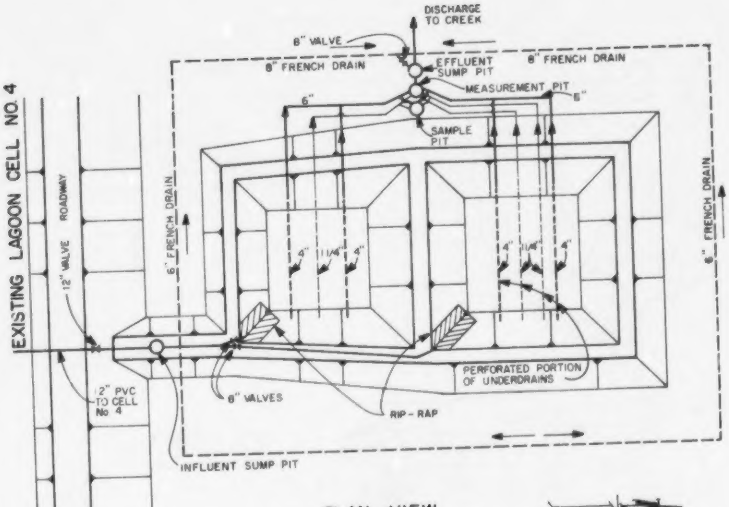


FIGURE 2
REUSE OPTIONS FOR LARAMIE, WYOMING
PROPOSED INFILTRATION/PERCOLATION BEDS
DISCHARGE TO RIVER
PUMP STATION
WINTER STORAGE
UPGRADED AERATED LAGOON SYSTEM
FORCE MAIN
N
REUSE OPTION "A" IRRIGATION OF MUNICIPLE LANDS
RIVER PARK
LARAMIE
UNIVERSITY OF WYOMING
REUS "C" DISC FOR
REUSE OPTION
UPSTREAM WATER TREATMENT PLANT
Spring Creek
LARAMIE RIVER
20
21
27
28
32
34
3
5

Figure 2


DISCHARGE TO CREEK
8" VALVE
8" FRENCH DRAIN
EFFLUENT SUMP PIT
8" FRENCH DRAIN
MEASUREMENT PIT
6"
8"
SAMPLE PIT
EXISTING LAGOON CELL NO. 4
ROADWAY
12" VALVE
6" FRENCH DRAIN
4"
11/4"
4"
4"
11/4"
4"
6" FRENCH DRAIN
PERFORATED PORTION OF UNDERDRAINS
12" PVC TO CELL No 4
8" VALVES
RIP - RAP
INFLUENT SUMP PIT

PLAN VIEW
LARAMIE PILOT PLANT

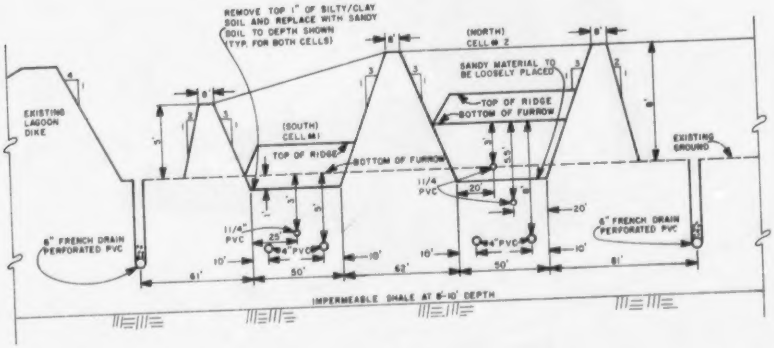

REMOVE TOP 1" OF SILTY/CLAY SOIL AND REPLACE WITH SANDY SOIL TO DEPTH SHOWN (TYP. FOR BOTH CELLS)
(NORTH) CELL # 2
8'
8'
8'
SANDY MATERIAL TO BE LOOSELY PLACED
EXISTING LAGOON DIKE
4
1
2
1
3
1
3
1
3
1
3
1
2
1
5'
8'
(SOUTH) CELL # 1
TOP OF RIDGE
BOTTOM OF FURROW
TOP OF RIDGE
BOTTOM OF FURROW
EXISTING GROUND
11/4 PVC
20'
20'
3'
5.5'
8'
1'
3'
3'
11/4" PVC
25'
4" PVC
4" PVC
6" FRENCH DRAIN PERFORATED PVC
6" FRENCH DRAIN PERFORATED PVC
10'
10'
10'
10'
61'
50'
62'
50'
81'
IMPERMEABLE SHALE AT 8-10' DEPTH

Figure 3

CROSS SECTION VIEW
LARAMIE PILOT I/P BED

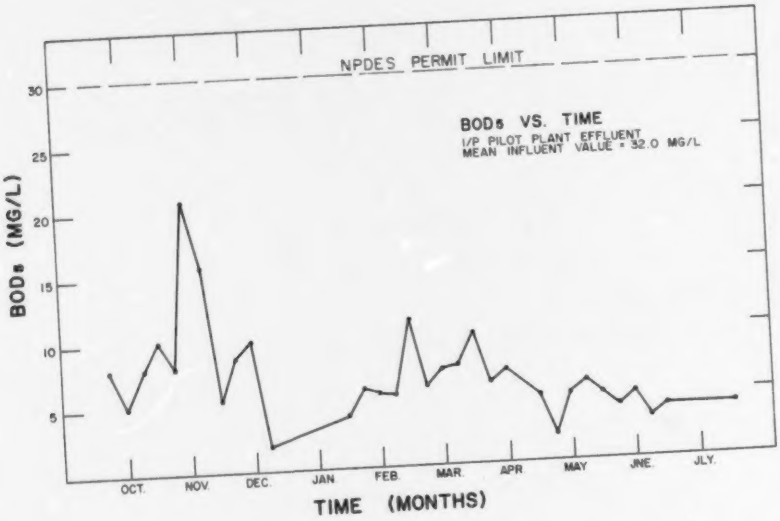


Figure 4

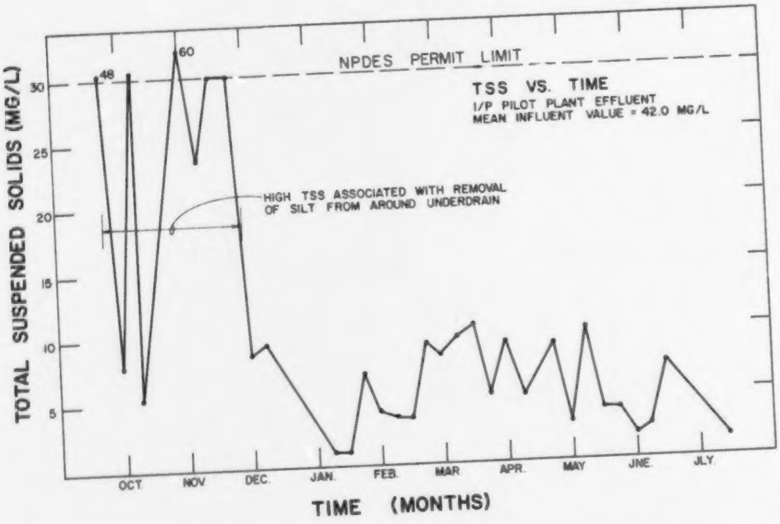


Figure 5

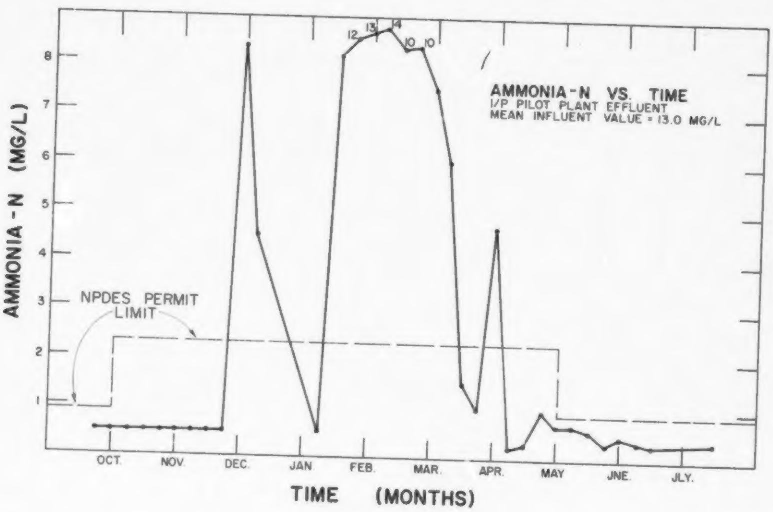


Figure 6

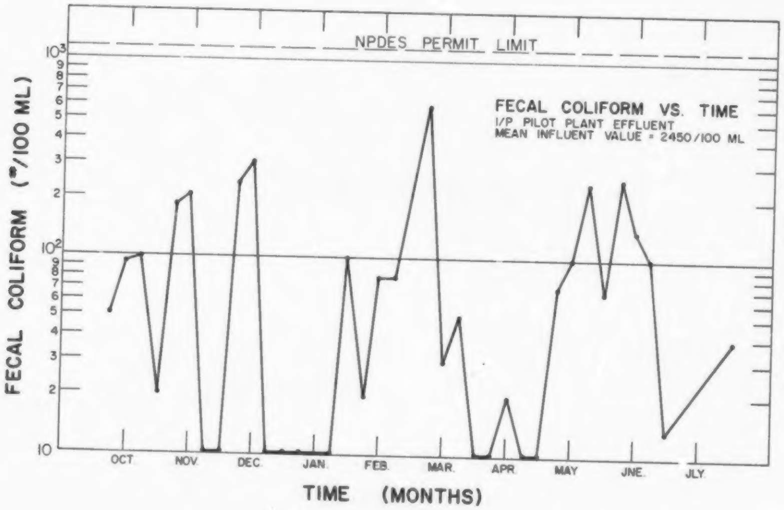
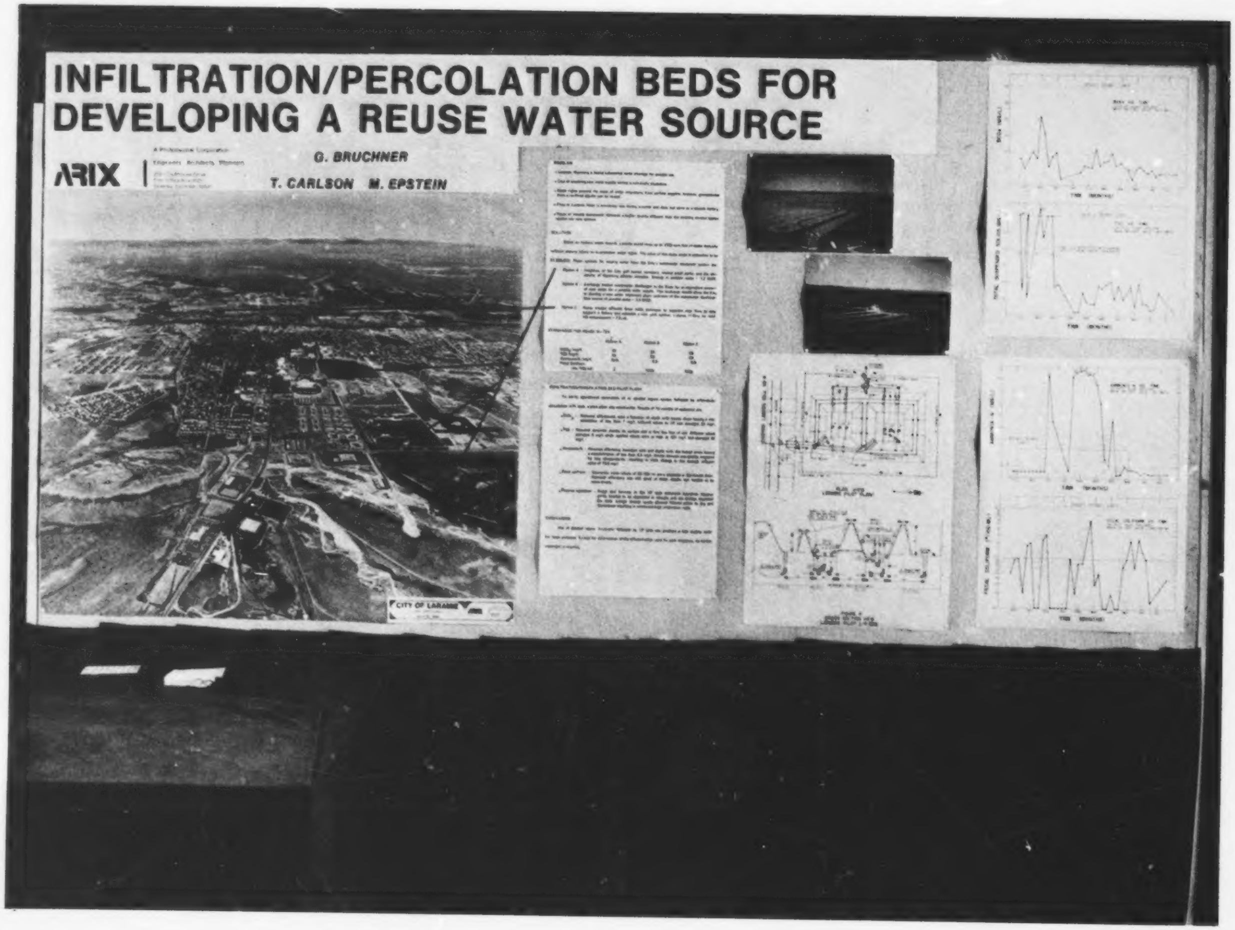


Figure 7



THE CASE FOR INTERDICTION

Ralph E. Whittaker, Jr.
President
ARCO Environmental, Inc.
Aqueonics Division
6905 Sierra Court
Dublin, CA 94550

The water needs of the United States today in the lower 48 parallel on a national basis the petroleum needs of nations which are without national petroleum reserves, known or unknown. There are portions of the United States which are water short and which must look to other geographical areas for the purchase and transport of water to serve their drinking, industrial, agricultural, social and economic needs. Just as in petroleum where nations look to outside sources for supply, these various states and areas must look to sources of supply which are out of their general sphere of influence and control. Such geographical areas in the U.S. are most generally referred to as Sun Belt areas or states and leave a deficit in water avails which necessitates their importation of water from surrounding areas or a potential future deficit for which specific supply must be located.

Such water shortages and the geographical areas in which they naturally occur are well known. These areas are sustained at current levels by use of a wide network of canals, dams, dikes and rivers built over a period of many years at large cost for pumps, pipe, concrete and steel as well as the cost for land to provide storage and aquaduct rights-of-way. With few exceptions, such distribution over many past decades has operated well and has provided sufficient supply for industrial development where other natural resources made such development commercially viable and made agriculture flourish where weather and climate when combined with irrigation established a profitable industry. Such water distribution has operated virtually unnoticed for the past 50 years.

Three things, however, now make a change in such operation inevitable. The initial change was the significant increase in energy costs imposed upon the electrical utilities and hence to the energy consumer. The second change is the continued discharge from underground aquafer of 23 billion gallons per day in excess of replacement. This negative balance makes inevitable the time when suitable volumes of surface avails must be found to replace the exhausted underground resources. The third change is the continuing shift to and population growth in the water short geographical areas of our country. The "sun belt" growth reflects a consumption need moving from water plus areas to water short areas. In short, three major factors (1) high energy cost for pumping and movement, (2) depletion of underground aquafer, and (3) heavy population shift and growth to and in water short areas, mandates a new and innovative approach to water supply.

This innovative approach is called Interdiction and has been developed by Aqueonics Division of ARCO Environmental to serve several of its customers. A 200,000 GPD water treatment plant has been designed, engineered and is under construction to collect 200,000 GPD of raw sewage from an existing sewer line, reclaim this water to specifications and quality required in Title 22, California State Water Control Board, for irrigation use in an adjoining home development currently under construction. The water quality required by Title 22 for such end uses is essentially as follows:

Spray Irrigation:	Adequately disinfected, oxidized, coagulated, clarified and filtered coliform 2.2/100ML
Surface Irrigation:	Adequately disinfected, oxidized coliform 2.2/100ML
Landscape Irrigation for Golf Courses, etc.	Adequately disinfected, oxidized wastewater coliforms 23/100ML
Parks, Playgrounds, School Yards:	Adequately disinfected, oxidized, coagulated, clarified, filtered wastewater coliforms 2.2/100ML

Such water quality is attainable from Aqueonics' designed water treatment plants utilizing feed waters containing residential and light industrial waste -- similar in nature to the chemistry of wastewater entering a high percentage of the usual extended aeration or activated sludge plants currently serving most areas of the country. The positive findings in the report, "Implementation of the Federal Water Pollution Control Act," (Committee Print 96-71) noted that toxic organic and heavy metal pollutants are present in wastewater discharges to a far less extend than previously feared. Second, it was found that conventional biological treatment technologies had been found to be capable of treating and removing toxic chemicals. These findings significantly affect new plant cost projections, capacity needs, and new plant engineering.

Possibly the greatest direct waste of energy and/or public monies today could be the existing programs which require the construction of water treatment plants to clean up nontoxic, non-heavy metal containing water to a specified quality of 20 BOD and 20 suspended solids as specified in the EPA letter dtd. March 1979 and then pump such effluent into a saline environment such as the Atlantic Ocean, Gulf of Mexico, Pacific Ocean or San Francisco Bay. Consistent with this effluent volume we are pumping, again at high energy levels, an ever increasing volume of new water to treatment plants as source or carrier for more residential waste to be again pumped and salt water contaminated. We are rapidly exhausting these "new water" sources.

Consideration must be given in any discussion of Interdiction to the question of salts. Human pass-through or consumption adds about 350 PPM to that amount present at time of passage through a potable water plant. Salt levels above 700 are on the high side of usefulness for land irrigation except where crop rotation can be useful in a planned rotation cycle. Some blending or the use of equipment as currently planned in Aqueonics Interdiction Plants are advisable to provide assurance that all aspects of the environmental cycle have received the attention necessary.

Interdiction technology today can make available to water short areas plants that can recapture wastewater from existing collection systems, process this water on small land plots with little odor or noise pollution and return the water to the community in a form and quality useful for all applications wherein specifications are contained in Title 22. Typically

	Influent	Effluent	% Red. Average
BOD	250	8	95%
SS	250	9	94%
TKN	28.0	4.9	83%
Total Coliforms[1]	--	2.2	--

1. Chlorination or chlorination/ozonation to meet Pomona Virus Study and Title 22 coli requirements.

Aqueonics currently operates plants with data from October 1979 on a 25,000 GPD plant and from January 1980 on a smaller pilot facility which provide the data base for interdiction plants currently under construction.

The final need for Interdiction is a short consideration of Public Law 92-500 and the multi-billion dollar funding as noted below

PUBLIC LAW 92-500 AND SUBSEQUENT AMENDMENTS: OBLIGATIONS AND OUTLAYS[1]
(in dollars)

Fiscal Year	Authority	Allotments	Obligated (Each FY)	Outlays
1973[a]	5,000,000,000	2,000,000,000	1,532,048,571	0
1974	6,000,000,000	3,000,000,000	1,444,443,360	158,816,688
1975	7,000,000,000	4,000,000,000	3,616,168,130	874,158,134
1976[b]	0	9,000,000,000	4,813,639,424	2,563,497,940
1977[c]	1,480,000,000	1,480,000,000	6,663,832,006	2,710,444,759
1978	4,500,000,000	4,500,000,000	2,300,916,959	2,959,897,559
1979	5,000,000,000	4,200,000,000	3,871,696,000	3,612,400,000
1980	5,000,000,000	3,400,000,000	1,765,000,000	3,274,100,000[d]

[1] Does not include reimbursable funds.
[a] Contract authority.
[b] Includes transition quarter (July-September 1976).
[c] Includes $480 million under Public Works Employment Act.
[d] Includes reimbursable and old law projects.

Source: Clean Water Fact Sheet, July 1980.

which confirms the expenditure to clean up used water and exhaust it in a cleaner condition into an expensive conduit for rapid removal from the location where it was contaminated and into another water body. The more rapidly we remove this unclean water, the greater load we place on the replacement sources and distribution system. Interdiction is the implementation of Section 201(g)(5) of the Clean Water Act of 1977 which requires all facility plans initiated after September 30, 1978, to consider innovative and alternative technology for municipal wastewater treatment in order to meet the national goals of (a) greater recycling and reuse of water, nutrients, and natural resources; (b) increased energy recovery and conservation, reuse, and recycling; (c) improved cost-effectiveness in meeting specific water quality goals; and (d) improved toxics management. The act also requires the set aside of a percentage of the state allotment (2 percent in FY79 and FY80 and 3 percent in FY81) and to increase the federal share of grants for I/A processes from 75 percent to 85 percent. Moreover, the Act provides for grants to pay 100 percent of the cost to modify or replace innovative or alternative technologies that have failed. The three-year I/A program as presently mandated by Congress will expire on September 30, 1981.

This Interdiction policy will make it possible to retain, at the basic point of origin, sufficient water of an acceptable quality to satisfy that area's need for nonpotable water, i.e. irrigation, industrial and commercial cooling, and process flow water, and for restoration of natural wildlife areas suffering from dimunition caused by water needs.

Interdiction suggests the recognition of wastewater as a local resource and the conversion of this resource through use of advanced technology into reuseable product which has significant value. In addition to a present worth on the resource is the subsequent reduction in additional potable water equipment needs, wastewater plant needs and in wastewater plant effluent disposal costs (pumping to disposal area). Interdiction is an innovative, cost-effective solution to population growth in water short urban areas which are currently exporting large quantities of partially treated water to uses which do not include set aside for nonpotable water end use.

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1. Title 22, State of California.
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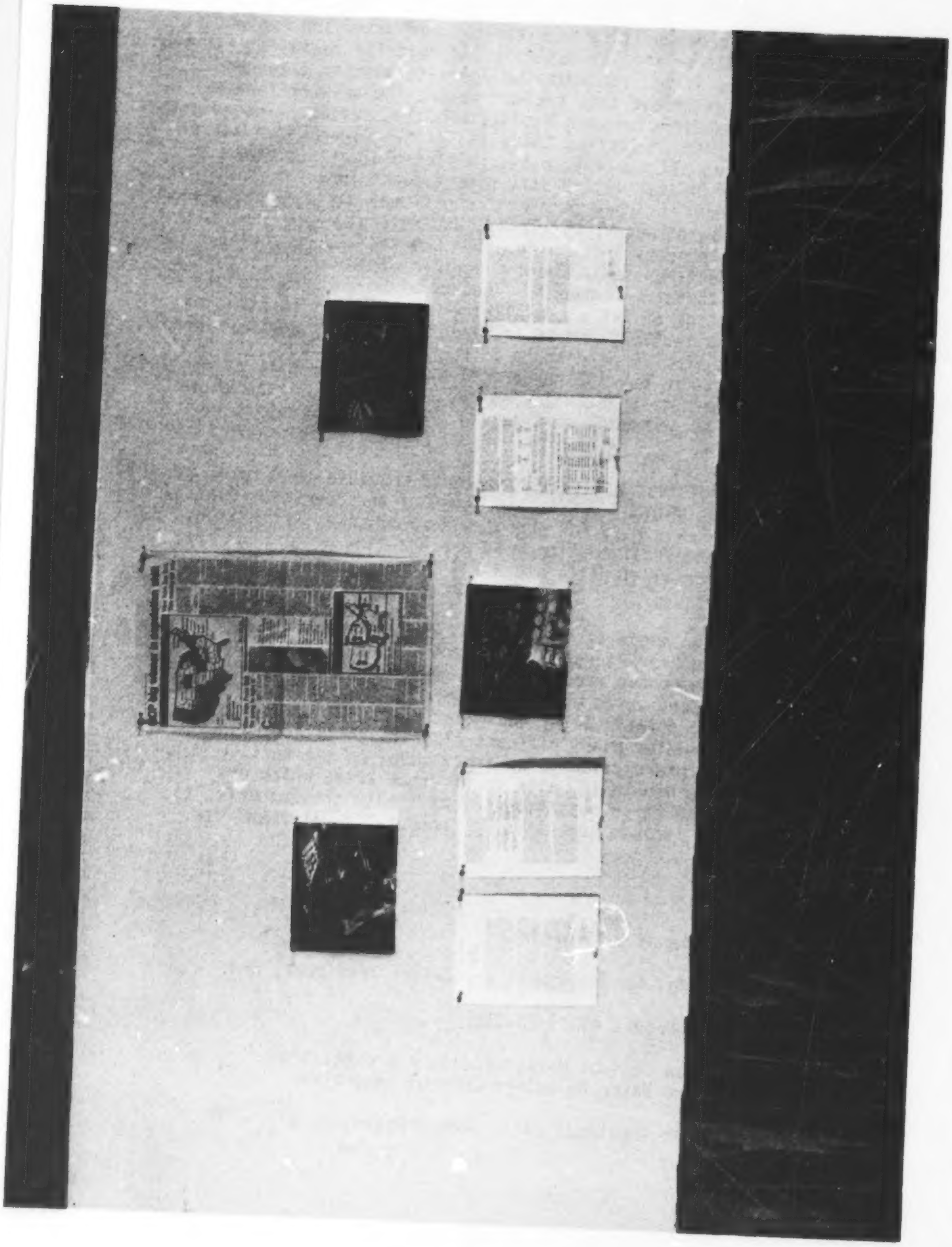
4. Water Pollution Control Market Facts, a presentation prepared by the Water Pollution Control Federation.
5. Aqueonics Plant Treatment Data, John McBride, et al.



WATER REUSE
SYMPOSIUM II

WATER REUSE AROUND THE WORLD

PB82-223314

THE DEVELOPMENT OF THE WASTEWATER REUSE PROGRAM IN ISRAEL

Hillel I. Shuval
Professor of Environmental Health
School of Public Health
Hebrew University-Hadassah Medical School
Jerusalem, Israel

Israel, with a population of 3.6 million, is facing severe conditions of water scarcity and in 1981, was utilizing essentially all of its economically available renewable water resources. By the year 2000, with an estimated population of 5.6 million, there will be a serious gap between available resources and water requirements as shown in Fig. 1. For the present, desalination of seawater is not an economically feasible option, but an extensive program of wastewater reuse will help close the gap.

As early as 1956, Israel's water planners included wastewater reuse as an important element in the national water resources plan and today Israel is one of the few countries in the world were full reuse of urban and industrial wastewater has become a matter of national policy.

Most wastewater reuse is for agricultural purposes with limited reuse of municipal wastewater in industry. However, a high percentage of the industries in the country practice intraplant reuse.

In 1981, some 30% of the flow of domestic wastewater from sewered areas was reused. Israel has pioneered the use of low-cost oxidation ponds for most of its small scale agricultural reuse projects.

The Dan Region Wastewater Reuse Project which will serve the greater Tel Aviv urban area with an ultimate design population of some 1.5 million persons is presently in the advanced stages of construction and should go on line by 1985. Although this large scheme involving biological treatment and ground water recharge and recovery was originally concieved as a project which would provide water for municipal reuse, it has been decided on health grounds to limit its effluent to agricultural and industrial uses. Since in any event, some 70 percent of the country's water is allocated for agricultural purposes, municipal reuse could be postponed for the forseeable future. Thus, drinking quality water from the National Water Project currently used in agriculture will become available for municipal use when it is replaced by high quality wastewater from the Dan Project which can be used for unrestricted agricultural purposes.

A major program of interseasonal storage of wastewater in large open reservoirs has been initiated to allow for accumulation of winter flows during the rainy season for intensive agricultural use during the dry summer irrigation months.

The trend of reuse of urban wastewater to date and projections to the year 2000 are shown in Fig. 2. It is anticipated that by the turn of the century, some 80% of the countries actual wastewater flow will be recycled.

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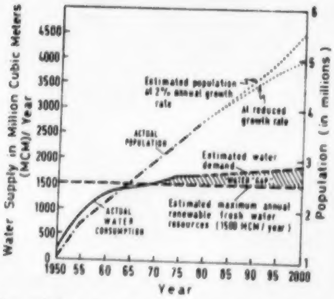

Fig. 1. Estimated population growth and water demand to the year 2000. Sources of data: Central Bureau of Statistics and Center for Economic Planning; and Tahal (1977). The Water Economy—Development and Management.

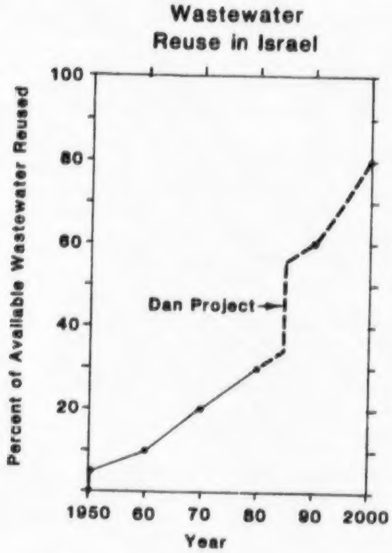

Fig. 2 Actual and projected reuse of wastewater in Israel as a percent of available domestic wastewater flows.

SOUTH AFRICAN WATER REUSE POLICY AND ITS PRACTICAL IMPLICATIONS

Axel F. Zunckel
Maria P. Oliveira
Pollution Control Division
Department of Water Affairs, Forestry
and Environmental Conservation
Pretoria, South Africa

INTRODUCTION

Water Reuse policy in the Republic of South Africa has evolved, as it no doubt has in other countries, as a matter of necessity rather than an imposition due to legislation, although the latter has also played its part. Case histories of successful reuse show strong evidence of "economic incentive", rather than "local sacrifice in the national interest". This development is obviously healthy in a free economy, but ever-increasing demands on the country's limited water resources dictate that individual interests will have to step in line with a national reuse policy if there is to be sufficient water of acceptable quality to maintain the country's current growth rate.

While reuse of purified sewage effluent (PSE), which has been subjected to advanced treatment (AWWT) is obviously attractive and has been the talking point at conferences for many years now, it is felt that it should not be allowed to over-shadow equally attractive reuse possibilities.

The concepts of reuse, recycling and economizing on water use are accepted by one-and-all in a country whose every citizen has come face to face with a water scarcity on occasions, but the practical implications and limitations of implementing such concepts are all too often lost sight of. In order to succeed, reuse policy must embody a total strategy in which wastewater is looked upon as one of the few remaining exploitable sources of water.

HISTORICAL EVOLUTION OF WATER REUSE POLICY

South African water law is based historically on the tenets of Roman-Dutch law. The application of a law originating in countries with such a vastly different climate and water regime to that experienced locally, led to obvious difficulties. Consequently the law was gradually modified through opinions of the courts up to the date of its codification in the "Irrigation and conservation of Waters Act, 1912".

The 1912 Act considered water used for maintenance of animal life (stock watering) and use for domestic purposes to be primary use.

Irrigation was regarded as secondary use while use for mechanical or industrial purposes was considered to be tertiary. It is amusing to note that the use of water in brandy distilleries ranked in importance with use for irrigation!

Nevertheless this early act provided no incentive for reuse and made no reference to sewage disposal although it did imply that any water returned to a public stream should be fit for human consumption, which appears to be rather a tall order in the light of present-day potability criteria!

In this context it is amusing to note the practical views of the district surgeon of Pietermaritzburg (1) in the 1850's in his defence of the open furrows or "sluits" running in front of the houses from which residents drew their domestic supplies or irrigated vegetable gardens. Dr. Samuel Gower preferred "fresh running water, openly exposed to sky and sun to that conveyed in wood, iron or lead pipes which might bring tadpoles, earwigs, cockroaches and small fishes, reptiles and insects into our tea and coffee". And yet another profound statement by Dr. Gower : "It is better to have your coffee made from water in a sluit that a horse has been drinking from, than with water that a horse has refused to drink". This must surely have been one of the first attempts at the use of biological indicators of pullution!

The Public Health Act, 1919 (Act 36 of 1919) prohibited pollution of water supplies for drinking and domestic purposes. In practice this led to the irrigation of raw or settled domestic effluent on the "sewage farms" which were so common in the early part of this century. As communities grew and housing developed in the proximity of sewage farms, so complaints of odour nuisance were raised. This encouraged larger local authorities to apply some form of biological treatment to produce a stable, odour-free effluent for irrigation. As time went by and sewage flows increased, the area available to local authorities for effluent irrigation became a limiting factor. This was brought to a head in 1940 when a Mr Vucinovich charged that seepage from Johannesburg City Council's sewage farm was polluting his borehole. The supreme court ordered that seepage should be contained within the boundaries of the sewage farm and, if this was not practically possible, seepage should be diverted to a river.

It soon became obvious that uncontrolled compliance with the supreme court ruling by an increasing number of local authorities could lead to degradation of the country's limited surface water resources. This point of concern promoted the then Institute of Sewage Purification to approach the government with the request that control of purification plants and disposal of effluents be vested in a central authority.

The Water Act, 1956 (Act 54 of 1956) (2) took all the aforementioned factors into account and in addition, placed a very strong emphasis on riparianism.

The act, as it applies to water use and effluent disposal, has been discussed in detail by Rudd, (3) but as far as water reuse is concerned, the underlying principle of the act and its implementation can be summed up as follows :

"Make use of the minimum quantity of water of the lowest acceptable quality for any process. Purify the resulting wastewater to a specified effluent standard and return the purified wastewater to the stream from which it was abstracted for the enjoyment of lower riparian owners."

This principle is expressed in the following sections of the 1956 Act.

1. Industrial Water Use

Section 12 of the Water Act stipulates that industries which intend using more than an average of 250 m^3 per day or whose maximum daily usage will exceed 300 m^3, must apply to the minister for a permit to do so.

This enables the department to actively encourage water conservation and reuse in industry. In particular, the reuse of purified domestic effluent in industrial processes and hierarchical use of water of progressively poorer quality within and between industries, is encouraged.

2. Purification : Industrial Effluents

(it should be noted that waterborne domestic effluent is considered to be "industrial effluent" for the purposes of the act).

Section 21 of the Water Act specifies that the purification of wastewater produced by the use of water for industrial purposes must form an integral part of the process. This establishes the "originator principle", namely that the polluter must pay for pollution control measures. The cost of such measures will be reflected in the price of his product and will, therefore, be a consideration in determining the viability of any project. In the case of domestic wastewater, the contributors alone pay for treatment and disposal of their wastewater.

(a)Effluent Standards :

The act empowers the minister to prescribe standards in respect of certain areas, rivers and catchments, or in relation to specific industrial types. Three such standards have been promulgated to date :

(i) a "special standard" (4) which applies to effluent discharged to mountain streams capable of supporting trout;

(ii) a "general standard" (4) in respect of effluents discharged to any other stream or to the sea;

(iii) a "nutrient standard" (5) which limits the soluble ortho phosphate content of effluents discharged in defined "eutrophication-sensitive" catchments.

South Africa has consistently applied effluent standards as opposed to stream standards.

(b) Relaxation of Standards :

Section 21(5) of the act makes provision for effluent dischargers to apply for exemption from compliance with the standards.

Such applications for exemption are considered with due regard to the practicability (or otherwise) of complying with the standard by making use of best available technology, the economic implications and the effect of such discharge on the receiving water.

Any standards, or relaxations thereof, must carry the approval of the S.A. Bureau of Standards. Depending on the circumstances, it is common to consult other expert bodies such as the Directorate of Health, Sea Fisheries Research Institute, Soil and Irrigation Research Institute, the National Institute for Water Research of the C S I R , etc. prior to granting exemption from standards. It is important to note that, since effluent permits specify a volume limit as well as quality, the question of pollutant "load" is covered.

3. Disposal of Effluents

Section 21(2) specifies that effluent, after purification, "shall be returned by the user at the nearest convenient point to the bed of the public stream from which the said water was abstracted or, if it was abstracted from the sea, to the sea".

This is in contrast to current thinking to the U.S.A. (6) which encourages direct reuse of effluents on land. South African policy is the legacy of historically entrenched water rights in a thirsty land in which water in most rivers and streams has been allocated to various users or belongs to riparian landowners.

Thus irrigation with purified sewage effluent is only permitted in cases in which :

(i) It is uneconomical for a water user to purify the effluent to a quality which could be discharged to a stream (generally local authorities with populations of less than 5 000).

(ii) The user has existing rights to river water which he forfeits in favour of using effluent.

The health aspects which apply to irrigation with purified or partially purified sewage effluents are covered in a guide issued by the Directorate of Health. (see Appendix 1)

A local authority may also, with the permission of the minister (section 22 of the act) use purified sewage effluent for purposes such as irrigation of parks and gardens in substitution for potable water, or may supply the purified effluent for industrial reuse.

4. Direct Reuse of Domestic Effluents subjected to AWWT :

The prime example of direct reuse for potable purposes namely at Windhoek (SWA/Namibia) has been well documented, (7) as have the operation and process refinements of the Stander AWWT plant in Pretoria. (8) Certain regions of South Africa are now rapidly approaching the state where domestic effluent after AWWT may have to be blended with conventional water supply for potable reuse. The Directorate of Water Affairs views the Manual for Water Renovation (8) and Hart (9) as a compendium of South African state-of-the art and consequently :

(i) has confidence in the ability of AWWT technology to produce water of a high (potable) quality from secondary sewage effluent.

(ii) shares concern with regard to the ability of AWWT plant operators to run sophisticated processes at high efficiency at all times and therefore realizes the need to build adequate safeguards into the system.

(iii) doubts the applicability of conventional drinking water standards to water abstracted from a highly polluted source (direct or indirect reuse) and therefore realizes the necessity for eliminating potentially harmful industrial effluents from a reclamation source (10) (11) and believes that drinking water standards should be reviewed continuously.

(iv) preferentially promotes reuse in non-critical applications such as industrial cooling and irrigation, rather than direct reuse for potable purposes, where practically possible.

(v) subscribes to the concept of "calculated risk" as opposed to "no risk" and consequently accepts that reclaimed water may be made available for direct potable reuse, with the necessary safeguards, where and when the need exists.

Van Rooyen (12) formulated recommendations for direct reuse :

"In the light of the present knowledge available, the Department of Health will give sympathetic consideration to direct reuse with the following as guidelines:

- No alternative economically feasible conventional supply is available.

- Only sewage of domestic origin should be used - The sewage water should contain the absolute minimum of industrial effluent of which the composition is known. An adequate control system to monitor industrial effluents ("Catchment Quality Control") is recommended.

- Only treatment and purification processes which have evolved through the many years of research should be used. If a changed process is contemplated, the change must be backed by the necessary research.

- An absolute necessity is properly trained and experienced personnel of various categories who are in constant attendance. This means full-time supervision.

- Serial monitoring of water quality after passing through treatment processes. These processes were evolved by the researchers to provide a system of multiple safety barriers. We should be sure that they in fact always do what they are supposed to do.

- Enough storage capacity for purified water should be available to allow for adequate retention time pending the monitoring results by amongst others, independent laboratories with experience in these matters.

- As an additional safety measure, it is recommended that reclaimed water should be diluted and thoroughly mixed with conventionally treated water to a ratio of not more than 20% reclaimed water to 80% conventionally purified water. This can be revised as our knowledge increases.

- On-going epidemiological surveys will have to be done in the areas supplied with reclaimed water. Base line studies prior to such a project are regarded as highly desireable.

- The whole issue of direct reuse is a sensitive one and the public must at all times be assured that it is exposed to a safe water. For this reason, it will be necessary to adhere to these recommendations. However, it is absolutely necessary that the public should be informed about all aspects of utilization of reclaimed water. The public should not be kept in the dark about anything. Any informed public is of utmost importance. This can hardly be overstressed."

5. Subsidies

Funding of industrial purification measures is carried by individual industries. The granting of long-term loans to local authorities is controlled by the four Provincial Governments, which encourage rationalisation of sewage purification systems in a given catchment.

The state does not subsidise plants which treat effluent to the gazetted quality standards. However, the Water Act does make provision for subsidies. It is the future intention to grant aid to users who will purify effluent in cases which will promote regionalisation of treatment facilities and reuse of renovated effluent.

SOUTH AFRICA'S WATER BUDGET AND POSSIBILITIES OF IMPROVEMENT

Geographically South Africa falls within the southern hemisphere's semi-arid belt and consequently a paucity of natural water resources is to be expected.

The most recent estimate of the country's exploitable water resources places the figure at 34 000 X 10^6 cubic metres per annum (13).

Three authoritative estimate of water demand have been made in the past decade (13) (14) (15). The latter two estimates, which have drawn from more up-to-date data, are only marginally more optimistic than the first (Table 1). Further information on projected demand of various sectors is reflected in Table 2. It is obvious from Table 3 that irrigation represents by far the greatest "loss" of water from the utilization cycle. While on-going efforts are in progress to improve the efficiency of water used for irrigation, it is likely that any savings would be utilized to increase food production by the irrigation of more land. Table 4 represents more recent information on the utilization of sewage effluent and the potential quantity available for reuse than that shown in table 3. This shows a disappointing potential 56 percent PSE available for reuse on a countrywide basis as opposed to 70 percent estimated previously. However, once the phasing-out of traditional PSE irrigation schemes on non-riparian land has been completed the quantity potentially available for reuse will approach 60 percent of the total intake and 74 percent of intake water to populations of more than 5 000.

In short therefore, on the basis of currently available data and taking all known trends into consideration, national demand is likely to outstrip exploitable conventional supplies shortly after the year 2020. This situation already pertains on a regional basis and recent schemes for the supply of water to urban and industrial complexes are characterized by far-from-ideal impoundment sites, inter-basin transfer (with associated high pumping costs) and long canals and pipelines. If one couples this with declining water quality concomitant with population growth and all its associated activities, it paints rather a bleak picture. Various avenues have been and are still being explored in an effort to augment the existing resources (16). A summary of the methods is given in Table 5. The message is clear. Reuse of effluents represents the most immediately viable proposition in areas where "conventional" sources are running out.

CURRENT STATUS OF REUSE IN THE REPUBLIC OF SOUTH AFRICA

(a) Direct potable reuse :

No direct reuse is practiced in the country at this stage, but it is felt that the way has been paved for its implementation, when the need arises by extensive research and demonstration plants (8) and full-scale operational experience and epidemiological studies on the Windhoek plant (7) (17).

(b) Indirect potable reuse :

The phenomenon which Shuval (18) so aptly refers to as "covert" reuse, is extensively practiced in the country, but is difficult to quantify. Covert reuse can be sub-divided into "series" reuse (Figure 1 (a)) or "semi-closed loop reuse" (figure 1(b)). Combinations of both are common.

Both configurations get more "milage" out of available water supplies, but this credit has not been included in estimates of the national budget, although it has been alluded to (13) (15). Covert reuse is taken into consideration in estimating the water resources of a particular region, as illustrated later.

(c) Direct non-potable reuse of effluent :

Van Vuuren and Hart (7) listed reuse of effluents from some major towns and industries in 1978. Although there has been no significant change, Table 6 lists up-to-date information for the whole country.

(d) Reuse by recycling :

This is a vitally important factor in getting the most milage out of a given water resource. The specific water utilization of various users is shown in Tables 6 to 9 and comparision is made with world-wide figures where available (19). It should be noted that direct reuse of PSE produced on site, is considered to be in-house recycling. It is considered that the tables (6-9) provide ample evidence of an all-out effort on the part of water users to limit their consumption as far as is possible. In concluding this section, it is illuminating to take a brief look at the reasoning which results in a reuse option being adopted or rejected. The following case histories serve as illustrations :

(i) Direct Reuse of PSE for Cooling at Six Municipal Power Stations :

The technological acceptability of using PSE in conventional power stations has been known and applied in South Africa since 1938 (20). In the event of treatment failing to prevent micro-biological fouling, it is possible to shut down part of a station (one set) for cleaning. Natural draft cooling towers act as ammonia scrubbers. PSE represents an assured supply which costs the local authority nothing but conveyance and treatment with biocides.

(ii) Rejection of Direct Reuse of PSE for Cooling a Chemical Plant (21) :

A large ammonia plant near Johannesburg was commissioned using purified sewage effluent as make up in the cooling system. The plant had difficulty in bringing bacterial growth under control mainly because atmospheric contamination by ammonia rendered control with chlorine difficult. Free chlorine residuals could not always be maintained and the nutrient value of the ammonia coupled with the phosphate in the sewage gave rise to a tremendous growth in micro-biological populations. Biological fouling promoted corrosive attack in exchangers due to the production of sulphide by the sulphate reducing bacteria desulpho vibrio :

$$SO_4^{=} + 2H^+ \quad H_2S + 4\ (O)$$

$$Fe^{++} + H_2S \quad FeS + 2H^+$$

The plant eventually reverted to the use of fresh water for cooling tower make up when it was found that cooling water-related heat exchanger problems were the cause of a significant reduction of plant on line time.

(iii) Optimization of Consumptive use of Polluted Water by Process Selection (21) (22) :

In 1978 AECI a large South African chemical company commissioned a complex of inter-related plants producing carbide, acetylene, vinyl chloride and poly vinyl chloride at its factory at Sasolburg. Effluent control at this complex has followed the waste segregation and reuse, leak and spill containment and recycle philosphy. Diaphragm cell technology was used for the new chlorine plant not only for the absence of mercury emissions but also for the favourable conditions that this technology created for the recycle of effluents.

The overall reaction for chlorine production is :

$$2NaCl + 2H_2O \longrightarrow Cl_2 + H_2 + 2NaOH$$

For each ton of chlorine produced 0,52 t of water is consumed to yield 0,03 t hydrogen and 1,13 t of caustic soda (NaOH). The caustic soda produced has a concentration of about 48% so a further 1,22 t of water is shipped with the product making a total consumption of 1,73 tons per ton of chlorine. The caustic soda formed in the diaphragm cell is weak (11%) with about 16% unconverted salt. It is, therefore, necessary to concentrate the caustic soda solution in a triple effect evaporator at the same time removing the unconverted salt for recycle to the brine plant. The removal of 7,92 t water per t of chlorine as relatively clean process condensate, suitable for discharge in terms of the South African standards during this evaporation stage meant that an even more favourable water balance could be created for the recycle of effluent, the total potential being 9,65 t of effluent water per ton of chlorine. The philosophy adopted was therefore to use :

1. Effluents made suitable for recycle
2. Contaminated rain water
3. Process condensate
4. Rand Water Board water (potable water)

in that order to make the brine required for chlorine production.

Effluents recycled to the chlorine plant are those arising from the hydrogen chloride burner vent scrubber and process vent scrubber on the Vinyl Chloride plant, from the waste chlorine system and hypochlorite destruction reactors as well as spillage from containment areas in the plant itself.

(iv) Reuse of Renovated PSE in the Pulp and Paper Industry :

(a) SAPPI (Enstra Mill) has been using 25 000 m³/day PSE since 1970. The treatment plant which receives secondary sewage effluent and treats it to a standard required for manufacture of high brightness paper, was designed by the National Institute for Water Research of the CSIR. Basically it consists of pH-correction, dosing with alum and polyelectrolyte, dissolved air flotation and sand filtration. This water costs the company less than half of that supplied from the potable distribution system. (7) SAPPI is extremely satisfied with the trouble-free operation of the plant.

(b) Mondi Paper Company near Durban operates a 12 000 m^3 per day renovation plant which receives activated sludge effluent from Durban southern sewage works. This represents more than 85% of the mill's demand. The treatment plant consists of flocculation, foam fractionation, sand filtration and activated carbon treatment. Carbon is regenerated at the mill. Giampietri et al (23) stated that the sale of land to Mondi by Durban Corporation was conditional on the use of a minimum of 9 000 m^3/day of PSE.

Although there is little cost advantage to Mondi, it is interesting to note that on an occasion when Durban's water supply was interrupted for three days due to flood damage, Mondi's mill continued operating on renovated PSE alone! Another point worth noting is that Springs' PSE costs SAPPI 14 percent of the cost of renovated water, while Durban's PSE represents 43 percent of the cost of Mondi's renovated water. The reason for this discrepancy is that Durban, being a coastal city, discharges settled sewage to sea via a pipeline and had to build a special activated sludge unit to cater for Mondi's requirements.

(v) Process Selection for Nil Effluent Discharge :

(a) Sasol II and III oil-from-coal plants :

When the S.A. Coal, Oil and Gas Corporation (Sasol) decided to expand its activities some 5 years ago and thereby decrease South Africa's dependence on oil imports, it was faced with the following problems : (24)

1. Siting of the plants adjacent to a suitably large coal field, placed them within the catchment of the Vaal Dam which is the one source of low-salinity water for South African's industrial heartland, the Vaal Triangle.

2. High cost of raw and potable water, both of which have to be conveyed over long distances to reach Sasol.

3. Years of experience at the Sasol I plant which showed the insurmountable problems in trying to attain the legal quality standard for river discharge (4).

4. Lack of know-how, worldwide, on designing an oil-from-coal plant for a nil effluent situation.

The relevant costs which had to be taken into consideration are shown in Table 10, which highlights the following significant points :

1. Although renovation of industrial water for reuse appears to be costly, the alternative (treatment for river discharge) is even more so.

2. Raw water treated for cooling purposes approaches the cost of potable water, so re-cycling represents a real saving. Incidentally the raw water is of far better mineral quality than the potable source.

3. Purified domestic effluent (which had to be purified for river discharge) could be bled into the industrial reuse cycle when the need arose. In practice, the increased salinity of PSE and its chloride content in particular, place a constraint on reuse.

The choice was clear and the task onerous. A nil effluent plant was designed with recycle amounting to more than 50 percent of intake using the basic philosophy of collecting effluents of similar quality in a series of "conservation sewers" for example :

OWS - Oily water sewer
CSS - Clean stormwater sewer
DCS - Dilute chemical sewer
CCS - Concentrated chemical sewer
SWS - Sanitary waste sewer
PCS - Process conservation sewer

The contents of each sewer is channelled to a particular treatment/disposal option on the basis of its quality.

(b) Electricity Supply Commission's (ESCOM's) modern powdered-coal-fired thermal power stations :

van Eeden (25) has shown the relationship between feedwater quality, cycles of concentration, thermal efficiency, make-up water and losses (blow down, evaporation and windage). In short, if the feedwater is of suitable mineral quality to permit the desired number of cycles of concentration, thermal efficiency is increased to the extent that evaporation is minimised and blow-down is just sufficient for the absorptive capacity of the waste ash. This balance relies to a large extent on an Escom-designed softening and dealkalization system which the author (van Eeden) will elaborate on at this conference.

In all the examples quoted, economics and technological viability have been major considerations. However, it is of interest to note that economic considerations are frequently linked to cost of intake water and limits imposed on effluent quality. It is clear therefore that the legal control over quantity and quality of water used in industry places a powerful tool in the hands of the administrator for the promotion of reuse.

MARKETING RENOVATED WATER

Potable reuse :

As far as the direct reuse of renovated water is concerned it is accepted that the public must be fully informed of such a scheme prior to its inception. South African authorities obviously have much to learn, since public acceptance of renovated PSE has not been put to the test locally. The wheels have already been set in motion to launch an early publicity campaign which will hopefully ensure smooth implementation of the first direct potable reuse venture when the need arises.

Non-potable reuse :

The Municipality of Benoni (26) serves as a good example of a local authority which has recently embarked on a project to supply upgraded secondary PSE for industrial reuse. The Benoni Sewage Works consists of conventional biological filtration with a design capacity of 18 000 m³ per day.

The municipality has been supplying prechlorinated, sand-filtered effluent to three adjacent industries for many years. The biggest consumer, a steelworks, indicated that a larger quantity of PSE could be used, if the quality were improved and that phosphate, in particular, caused problems in respect of steel surface chemistry.

The promulgation of a legal limit on effluent phosphate content (5) in August 1980, provided the stimmulus for Benoni to embark on an investigation into the feasibility of extending its supply of renovated PSE to other industries in the vicinity. The municipality called in the National Institute for Water Research of the CSIR which put forward proposals for the production of 15 000 m³ per day of upgraded PSE with quality as shown in Table 11.

Viability of the scheme depends largely on the number of consumers that can be canvassed. In this respect the Directorate of Water Affairs is giving Benoni its wholehearted support and assistance and has commenced a market survey in a nearby industrial area (see Appendix 2).

A first-round survey of industries has been completed and the results thus far have been most encouraging. With the odd exception, industrialists have shown keen interest in the project and are currently conducting further in-house investigations with respect to cost and effect on processes.

Throughout the survey, although all relevant information (Appendix 2) was furnished to industries, the approach was kept as simple as possible. It was considered that the project would be doomed to failure if it were imposed on industry. Fortunately the price of the reclaimed PSE is such that it sells itself. Some pros and cons are listed below.

PROS	CONS
Water will cost 50% of current supply.	Dual piping system will have to be provided by the industry on its property. Pipes carrying reclaimed PSE must be distinctly coloured and signs must be erected to prevent employees from drinking it.
Assurance of supply will be ensured by adequate storage at the purification works and a ring feed system.	Use as boiler feed water will involve higher demineralization costs. High chloride content could lead to increased corrosion. (Chloride results from the use of Ferric Chloride in the renovation process)
Water will be at a pressure equivalent to that of existing supply.	
Reclaimed water quality will be high except in respect of some mineral constituents. (Table 11)	

A PRACTICAL EXAMPLE OF REUSE OPTIONS

The Pretoria-Witwatersrand-Vereeniging-Sasolburg complex (PWVS complex, see Figure 2) is responsible for more than half of South Africa's gross national product. Within this complex one encounters all the possible elements and problems associated with reuse. Cillie (17) discussed reuse in the development of this river basin in 1978. The 1980 White Paper (28) on extentions to the existing Tugela-Vaal inter basin water transfer scheme indicates that the regional demand will outstrip existing supplies early in the next decade.

Water will be delivered from the Tugela River into the Vaal River catchment at the completion of phase II of the scheme at a cost of 8,15 cents/m^3. It is expected that the incremental cost of any future water imported to the PWVS complex will be in the region of 16 to 20 cents/m^3.

Bulk water purification and distribution of water in the PWVS region is undertaken by the Rand Water Board (33) which supplied 693 X 10^6 m^3 of purified water to a population of just over 5 million and the associated mines and industries in 1978/79. The bulk of effluent return flows drain back into the Vaal Barrage which is the primary water source.

In spite of strict pollution control measures maintained in the region, the increasing proportion of return flow has led to a steady decline in (particularly) the salinity of water supplied to consumers. The Water Research Commission (34) launched an intensive study into the sources of salinity contributed to the system. A summary of the findings is presented in Figures 3 and 4.

A study on the effects of increase in the salinity of the Vaal Barrage (35) showed that an increase from the current annual average of 300 mg/ℓ Total Dissolved Solids to 400 mg/ℓ would cost the PWVS complex R 75 million per annum in terms of increased treatment costs, corrosion, detergent use, etc. An increase from 300 to 800 mg/ℓ about R 140 mil. per annum.

The Directorate of Water Affairs, in carrying out its responsibility to provide adequate water to the region, as dictated by demand, has realised that the maintenance of acceptable quality of supply is of utmost importance. It recently commissioned a firm of expert consultants to undertake a 3 year feasibility study into the control and reuse of effluents in the PWVS region. The study, which has been in progress for just over six months now, has brought the following facts to light :

(i) Direct reuse of effluent provides no relief in respect of the quantity of water required by the region (see Figure 5(a) and 5(b)). This is obvious since return flows are currently discharged to the Vaal Barrage, forming portion of the source.

(ii) As the demand rises the advantage due to direct reuse in respect of water quantity becomes evident. (see Figure 5(c)).

(iii) It is essential to remove salinity from the region ("salt sink" concept).

(iv) Table 12 shows that the pumpage of underground mine water from four points contributes 60% of the point salt load, also that non-point sources contribute 60% of the total annual salt load of 568 000 tons.

(v) While the concept of sidestream desalination by reverse osmosis (R.O.) following AWWT appears to be attractive, the magnitude of such a project must not be lost sight of, bearing in mind that some 150 mil. m^3 per annum of secondary PSE would potentially be available for renovation. Figure 4 shows that if one starts with 150 mil. m^3 per annum of renovated effluent at 800 mg/ℓ total dissolved solids and wishes to produce a blended supply of 300 mg/ℓ T.D.S., one has to treat some 72% of the total flow and losses some 18% as brine (27 mil. m^3 per annum), for which a suitable method of disposal must be found.

(iv) The elimination of system losses (Figure 3) would make a very positive contribution towards increasing the value of reclaimed PSE as a resource. However, if one takes a realistic look at the possibility of reducing losses, one finds that the potential is limited :

1. Domestic consumption (loss) can only be reduced by limiting the quantity of water used for gardening, car washing etc. This amounts to some 20 to 25%

of total domestic water intake. Application of a price disincentive would concievable eliminate truely excessive use. Any further reduction would represent a lowering of the standard of living which few people (the authors included) would be prepared to accept, no matter what the price.

2. In Industry, the only losses from the water cycle which can be expected are, in increasing order of magnitude : disposal of brines in solar ponds, combination with product (unavoidable), land disposal of medium salinity effluents and, the major loss, evaporative cooling.

   The reduction of evaporative cooling losses has been investigated in detail by S. Africa's largest "cooling organization", the Electricity Supply Commission (25) which has reduced its specific water consumption over the past 15 years or so by some 50 percent (see Table 8). The next power station planned will operate largely on dry cooling and will consume a mere 0,6 ℓ/kWh sent out as opposed to 5,2 ℓ/kWh in stations built in the 1960's; a saving of 88 percent!

   Alexander (22) has also indicated how the efficiency of cooling systems and use of cooling water treatment chemicals can be optimized in industry. It is considered that cooling system losses warrant further detailed investigation.

3. The major system water loss on mines is associated with the vast quantities of waste materials (tailings) which are conveyed hydraulically to final disposal in tailings dams. Although water is recycled, these dams represent vast evaporation areas as well as "sponges" which retain water. However, the salinity of this water is typically so high (3 000 to 6 000 mg/ℓ T.D.S.) that the tailings dams should be viewed as a salt sink from which water recovery does not appear attractive.

(vii) The cost of various treatment stages towards reclamation of PSE for potable reuse were extracted from various reference (7) (9) (23) (30) (31). An attempt was made to project figures to a common time base, 1981, by means of price adjustment indices.(32)

Due to lack of detailed breakdown of quoted cost figures, it was not possible to apply the adjustment indices on a weighted basis according to each component of the total cost. The next best alternative, namely a non-weighted average of price adjustment indices, was adopted (Figure 7).

The full cost (interest, redemption and running cost) of various treatment processes and capacity, adjusted to 1981 value are reflected in Figure 8. It should be noted that incremental costs are shown. Thus the treatment 20 000 m³ per day of raw sewage by means of conventional, AWWT and R.O. treatment would cost (Figure 8) in the region of 70 cents per cubic metre.

While this figure seems alarming, it should be remembered that

(a) Treatment of sewage effluent to "secondary standards" (4) (5) is legally required of the community and need therefore not be reflected in the total cost;

(b) Cost advantage can be gained by a tailored intregated design of AWWT and R.O. processes;

(c) The removal of salt from the regional water circuit to a "salt sink" will be a necessity in any event. The application of desalination to AWWT effluent should therefore be costed in relation to the overall improvement in salinity.

If all the above mentioned factors are taken into consideration, it is likely that potable water produced by a 100 000 m³/day AWWT/R.O. plant could compete in cost with that available from the next surface water source to be exploited.

CONCLUSION :

South Africa's 1956 water act embodies sound principles with regard to optimization of the water utilization cycle. This act is administered by one national authority, the Department of Water Affairs, Forestry and Environmental Conservation. In performing its task, the department draws on the expertise of sister departments and research organisations. It is felt that such centralized control eliminates the possibility of confusion with regard to reuse policy.

By virtue of its geographic location, S. Africa has had to contend with periodic water shortages throughout its history. The country's rivers exhibit extremely variable flow patterns and do not provide any surplus which could be used to dilute pollutants. This natural condition has created an awareness, at all levels of society, of the need to maximize the use of limited water supplies. It is considered that such awareness is the key to success, without which acts and policies would be to no avail.

Increasing demands on the already heavily taxed water resources necessitate the review of policies to cater for the water reuse era in which the country already finds itself. The many years of excellent basic research, pilot and demonstration plant studies into direct potable reuse of effluent have placed future exploitation of this resource on a sound footing. Direct reuse is but one of the options which should be considered in a holistic approach to water conservation.

Since large-scale direct reuse projects might be initiated in certain regions within the next decade, the authors consider this an opportune time to look at some future policy pointers as set out below :

(a) Policy should be directed towards the elemination of system losses in all use sectors. This would be achieved most simply, but not necessarily most effectively, by the application of cost disincentives. Dry cooling should be encouraged.

(b) Increase in the salinity of effluent should be viewed as a diminution of the value of the resource. Policy should be directed towards making the discharger pay the cost of desalinating water to a useable quality. This is particularly important in regard to industries discharging saline effluents to domestic sewers and relying on dilution.

(c) South African large-scale reuse projects will undoubtably rely to a greater or lesser extent on desalination. It is considered to be sound policy to provide a "salt sink" in such regions which would not only serve for disposal of desalination plant brines, but would bring forward all those who quietly throw their saline effluents down the drain.

(d) While the provision of special quality water in dual piping systems to certain large consumers warrants attention, it is considered totally impractical to attempt to cater for all quality requirements. General policy should be to supply a good average quality of water (about 300 mg/ℓ T.D.S.) to all consumers in a region. Acceptable salinity levels should be established with due regard to individual constituents.

(e) The elimination of high salinity peaks is considered to be of more value to consumers than the intermittent provision of very pure water.

(f) Desalination of AWWT plant effluent does not appear to be a cost effective method of salt extraction. High salinity mining and industrial effluents as well as non-point contributions should be the first to receive attention.

(g) Processes such as ash quenching and tailings conveyance which are capable of "consuming" saline effluents should be exploited as salt sinks.

(h) Non-additive processes, such as the use of reverse osmosis in preference to ion exchange for the preparation of boiler feed-water, should be encouraged.

(i) The campaign to phase out irrigation of PSE on non-riparian land, should be stepped up.

(j) Biological processes for removal of nutrients from sewage effluent are preferred to chemical precipitation, since they do not add to effluent salinity and are effective in removing nitrates which would otherwise pose a problem in a direct reuse system.

(k) The discharge of PSE to sea by coastal cities represents an irrecoverable loss. The local authorities should be made aware of their legal responsibility to produce secondary PSE at their own expense when the absence of other economically exploitable sources necessitates direct reuse.

(l) An on-going effort should be maintained to gather data necessary for quantifying all facets of re-use. In particular, acquisition of realistic up-to-date process costs is essential.

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TABLE 1 : COMPARISON OF THE MOST RECENT WATER DEMAND ESTIMATES FOR S. AFRICA ($10^6 m^3$ per annum) after Dekker (15)

USER	YEAR								
	1970			1975			1978		
	1*	2*	3*	1	2	3	1	2	3
Domestic, industrial and mining	1 687	1 600+	2 100+	2 256	2 025	2 900+	2 636	2 300+	3 600+
Irrigation	7 107	6 400+	8 000+	7 751	7 200+	8 700+	8 497	7 700+	9 000+
Stockwatering	157	(261)	91	173	(261)	108+	184	(251)	121+
Nature conservation	219	219	219	219	219	219	219	219	219
TOTAL WATER USE	9 170	8 480	10 410+	10 399	9 705	11 927+	11 536	10 480	12 940+

USER	YEAR								
	1980			2000			2010		
	1	2	3	1	2	3	1	2	3
Domestic, industrial and mining	5 063	3 961	8 200+	7 577	6 085	16 600	9 975	9 569	32 900+
Irrigation	10 776	9 880	10 800+	13 136	12 050	12 200+	16 013	14 680	14 752
Stockwatering	222	261	184+	261	261	261+	261	261	261+
Nature conservation	219	219	219	219	219	219	219	219	219
TOTAL WATER USE	16 280	14 321	19 403+	21 193	18 615	29 280+	26 408	24 739	48 132+

* 1. Division of Special Tasks (15)
2. Du Plessis and Van Robbroeck (13)
3. Commission of Enquiry into Water Matters (14)

+ Interpolated or extrapolated values

( ) Figure assumed by author (15)

TABLE 2 : WATER USE ESTIMATES FOR VARIOUS SECTORS (m^3 X 10^6/ANNUM) after BEKKER (15)

REFERENCE	USER (OR ITEM) :		"BEST ESTIMATE" DATA				PROJECTED DATA			
			1970	1975	1978	1980	1990	2000	2010	2020
D	URBAN AND RURAL DOMESTIC		1 139	1 589	1 903	2 138	3 829	5 946	7 990	9 740
E	MINING AND INDUSTRIAL NOT INCLUDED IN D		414	489	538	571	767	1 031	1 385	1 861
F	POWER STATIONS NOT INCLUDED IN D		134	178	195	240	467	600	600	400
C	TOTAL DOMESTIC, MINING AND INDUSTRIAL		1 687	2 256	2 636	2 949	5 063	7 577	9 975	12 001
B	IRRIGATION		7 107	7 751	8 497	8 840	10 776	13 136	16 013	16 013
G	STOCKWATERING		157	173	184	190	222	261	261	261
H	NATURE CONSERVATION		219	219	219	219	219	219	219	219
A	TOTAL-ALL USERS		9 170	10 399	11 536	12 198	16 280	21 193	26 468	28 494
	FORESTRY			(1 187)		(1 266)*	(1 425)*	(1 585)	(1 745)	(1 745)
P	POPULATION (10^6)		21,4	24,2	26,0	27,5	37,1	49,4	60,4	72,3
D/P	"DOMESTIC" UNIT USE	m^3/CAP/YEAR	53	66	73	78	103	120	132	135
		ℓ/CAP/DAY	146	180	201	213	282	330	362	369
A/P	TOTAL UNIT USE	m^3/CAP/YEAR	429	430	444	444	438	429	438	394
		ℓ/CAP/DAY	1 176	1 178	1 216	1 216	1 200	1 175	1 200	1 079

Forestry use expressed as a reduction in runoff which reduces total water resources which can be developed. This use is calculated as the excess use of forestry above that of the natural vegetation.

* Linear interpolation (20 000ha planted per annum)
The word "domestic" is placed in inverted commas to show that the use is not purely domestic - the urban use includes industrial use as well.

TABLE 3 : SUMMARY SHOWING WATER POTENTIALLY AVAILABLE FOR REUSE IN 1978

(Values X 10^6 m^3/annum) after Bekker (15)

CATEGORY OF CONSUMER	TOTAL WATER INTAKE	WATER * CONSUMED	WATER AVAILABLE FOR REUSE (irrespective of quality)
NATURE CONS.	219	219	NIL
AGRICULTURE + STOCK WATERING	8 680	8 680	NEGLIGIBLE
MUNICIPAL + RURAL	1 900	560	1 340
MINING	263	212	51
INDUSTRIAL	276	125	151
POWER GEN.	196	182	14
TOTAL	11 534	9 978	1 556

* consumed includes saline effluent stored in solar ponds and legal irrigation as a method of disposal rather than a means of profitable crop production.

TABLE 4 : DOMESTIC WATER UTILIZATION IN S. AFRICA SHOWING POTENTIAL FOR REUSE (UPDATED 1978 FIGURES)

CATEGORY ACCORDING TO POPULATION	TOTAL POPULATION (MILLIONS)	TOTAL WATER INTAKE (10^6 m^3 per year)	WATER IRRIGATED (10^6 m^3 per year)	WATER POTENTIALLY AVAILABLE FOR REUSE (Assume 25 percent loss) (10^6 m^3 per year)
RURAL AREAS	13,8	343,4	"lost"	NIL
LESS THAN 5 000	1,16	52,7	39,8	NIL
GREATER THAN 5 000	2,14	232,4	18,5	155,8
METROPOLITAN AREAS	8,9	1 274,5	46,8	909,1
TOTAL	26	1 903	105,1	1 064,9

TABLE 5 : POSSIBILITIES FOR AUGMENTATION OF CONVENTIONAL WATER RESOURCES (AFTER ALEXANDER (16))

POSSIBLE SOURCE OF ADDITIONAL WATER	METHOD OF EXPLOITATION	STATUS
ATMOSPHERE	Hygroscopic chemicals (LiCℓ most promise)	Energy required to recover product water from the hygroscopic chemical too costly.
	Refrigeration	Energy to reach dew point and overcome latent heat of condesation is too great.
	Fine mesh fog-condensation screens	Limited to areas experiencing frequent fog or low cloud. Coastal areas not suitable due to salinity.
	Cloud seeding	Research continues at high cost. Effects difficult to quantify. Objections of local community must be contended with.
INCREASING SURFACE RUN-OFF	Provision of impervious concrete areas	Limited to special applications ie. rocky islands in dire need of of water
	Application of hydrophobic chemicals to large surfaces .	Far too costly, not to mention the environmental impact which this might have. The concept has not been tried.
REDUCING EVAPORATION LOSSES	Evaporation-suppressant applied to open water surfaces.	Difficulty in maintaining film or floating slabs. Temp. rise causes greater evap. when film breaks. Radiation reflectants might overcome latter difficulty.
	Anti-transpirant	Effective in laboratory tests, but environmental consequences in large-scale application unknown.
INCREASING GROUNDWATER RECOURCES	Artificial re-charge	Extremely limited due to absence of primary aquifers (unconsolidated alluvium)

IMPORTATION OF WATER FROM THE ANTARTIC	Towing icebergs to S.A.'s shores	While desk studies show towing to be feasible, the cost and technological problems associated with processing the ice and getting it ashore are prohibitive.
MORE BENEFICIAL USE OF AVAILABLE RECOURCES	Long-term weather prediction	Research is on-going world-wide.
	Re-use of effluents	Most promising. Has immediate application.

TABLE 6 : DIRECT NON-POTABLE REUSE OF PURIFIED SEWAGE EFFLUENT

USER	ANNUAL QUANTITY REUSED (10^6 m³)	
	MAJOR TOWNS AND INDUSTRIES 1978 (after v.Vuuren & Hart (7))	WHOLE COUNTRY 1980
POWER STATION COOLING	39,3	50
INDUSTRIES AND MINES	31,8	38
IRRIGATION	72,5	105
TOTAL	143,6	193

TABLE 7 : SPECIFIC WATER UTILIZATION OF SELECTED TYPICAL MINES

SOUTH AFRICA 1980

Number of Mines surveyed	Type of Mine	Sources of Water	Production (tonnes of ore/day)	Water Usage (m^3/d)	Effluent discharge (m^3/day)	Consumptive Water Use (m^3/t of ore)		
						Minimum	Average	Maximum
3	Fluorspar	Potable + PSE	16 800	8 380	Nil	0.2	0.8	1.2
1	Tin	Underground + PSE	2 000	6 000	2 000	-	0.5	-
1	Copper + Phosphate Rock	Underground, Potable + PSE	75 000	60 800	22 000	-	0.6	-
1	Copper + Zinc	Potable, borehole + PSE	4 5000	11 500	Nil	-	2.6	-
1	Copper	Potable, underground + PSE	7 000	8 800	Nil	-	1.3	-
1	Phosphate Rock	Potable, underground + PSE	50 000	55 500	17 000	-	0,7	-
2	Chrome	Potable + underground	1 400	700	Nil	0,5	1,2	1,9
1	Diamond	Potable, underground, borehole + PSE	14 000	22 300	Nil	-	1,6	-
5	Gold*	Potable, underground + PSE	26 500	142 100	76 500	1,5	2,5	3,4
5	Gold + Uranium **	Potable, underground + PSE	68 500	255 100	30 300	0,5	3.3	5.4
11	Coal	Potable, underground + PSE	160 100	62 500	11 300	0.05	0.3	0.65

* 3 of these mines discharge domestic effluent into the municipal sewer.

** 1 of these mines discharge domestic effluent into the municipal sewer and another has no effluent.

TABLE 8 : SPECIFIC WATER UTILIZATION OF VARIOUS TYPES OF INDUSTRIES 1978
(unless otherwise specified)

Number of Industries Surveyed	Type of Industry	Production (t/day)	Total Water intake (m^3/day)	Specific Water Intake (m^3/t)		Effluent discharged (m^3/day)	Specific Consumptive Water Use (m^3/t)		
				South Africa	Elsewhere (19 (1969 figures		Min	Av.	Max.
3	Petroleum Refinery	46 115*	27 592	0,6	10	18 823	0,08	0,2	0,34
2	Oil from Coal	90 500	203 000	4,0	-	57 000	2,4	-	3,0
1	Phosphate + Sulphuric acid	2 455	14 500	5,9	-	3 814	-	4,4	-
1	Chlorine + caustic soda + chlorinated hydrocarbons**	211	2 500	11,52	125	Nil	-	11,52	-
1	Ammonia Nitric Acid Associated Products + Expliaives	6 685	46 741	7	-	18 060	-	4,3	-
1	Calcium Carbide + acetylene	2 464	6 200	2,5	-	1 330	-	1,9	-
1	Synthetic Rubber + Associated Products	147	2 250	15,3	-	1 141	-	7,5	-
1	Polyelofine	254	1 752	6,9	-	756	-	3,9	-
1	Chlor-Alkali Polyvinyl-Chloride	1 682	18 160	10,8	-	7 180	-	6,5	-
8	N & P Fertilizers	9 379	41 020	4,4	-	10 900	0,9	3,4	8,8
3	Steel	31 103	205 913	6,6	8 - 12	10 376	2,6	3,3	3,72
3	Special steels and Alloys	4 077	38 551	9,4	72	Nil	4,6	10,9	20,4
3	Fine Paper	764	20 780	27,2	200 - 1000	18 870	1,4	2,5	4,3
5	Packing Paper	949	36 050	38,2	125	27 310	1,3	9,8	37,0
1	Sulphate Pulp bleached	200	18 000	75	170 - 500	7 600	-	37	-
1	Sulphite Pulp	795	95 500	120	300 - 700	90 725	-	6,0	-
3	Newsprint Paper	700	23 050	33	165 - 200	21 170	2,4	2,7	3,5
2	Tissues Paper	114	4 660	40,9	-	4 380	-	24	-
4	Industrial Board	434	4 727	10,9	125	4 450	0,6	0,7	1,3
9	Conventional Chaingrate Power Stations	21,42ø	121 020	7,4	-	25 517	2,5	5,2	12
13	Pulverised fuel Power Stations	304,43ø	774 400	2,9	-	47 800	2,0	2,7	12
	Future Dry Cooling Power Stations	-	-	-	-	Nil	-	0,6	-

* Tonnes of raw material

** 1981 data

ø Units sent out expressed as Gigawatthour, specific water intake and specific consumption use expressed in litres per Kilowatthour.

TABLE 9 : INDUSTRIAL WATER INTAKE IN S. AFRICA AND ELSEWHERE

TYPE OF INDUSTRY	NUMBER OF INDUSTRIES SURVEYED	DAILY PRODUCTION UNLESS OTHERWISE SPECIFIED	WATER INTAKE (m^3/day)	SPECIFIC WATER INTAKE (m^3/unit)	
				SOUTH AFRICA 1978 FIGURES	ELSEWHERE (19) 1969 FIGURES
MOTOR ASSEMBLY	9	1 250 (cars)	7 365	5,9	38
ABATTOIR	1	458 (t)	13 540	29,6	4 - 25
CANE SUGAR	17	7 900 (t)	441 000	55,6	
WINE	22	22 300 (m^3)	30 300	1,4	2,9
TEXTILE (a) wool	1	3 (t)	150	50	400
(b) cottons + synthetic	7	66 (t)	17 281	350 - 900	
(c) cotton, wool + synthetic	5	54 (t)	7 678	60 - 750	
LEATHER TANNING	16	167 (t) (raw material)	3 880	5 - 170	
STARCH FROM MAIZE	1	115 (t)	850	7,4	13 - 18
FRUIT AND VEGETABLE	9	254 857 (t/year)	2 528 000 (m^3/year)	7 - 16	10 - 20

TABLE 10 : WATER AND EFFLUENT COSTS FOR VARIOUS USES, SASOL II JUNE 1981 (29)

TYPE OF WATER OR EFFLUENT	DESTINED FOR	COST IN $^c/m^3$		
		AS RECEIVED	ON-SITE TREATMENT	TOTAL
RAW WATER EX USUTU -VAAL INTER BASIN TRANSFER SCHEME	COOLING	11,7	2	13,7
	BOILER-FEED	11,7	15 - 20	27 - 32
POTABLE WATER EX RAND WATER BOARD SUPPLY	DOMESTIC	13,9	NIL	13,9
INDUSTRIAL EFFLUENT CAPABLE OF REUSE	MAINLY COOLING	(-50 or more) *	32 - 50	(NIL)
INDUSTRIAL EFFL. AS ABOVE	RIVER DISCHARGE IN COMPLIANCE WITH STD.	NIL	more than 50 *	50
DOMESTIC EFFLUENT	RIVER DISCHARGE IN COMPLIANCE WITH STD.	NIL	14	14

(* See text)

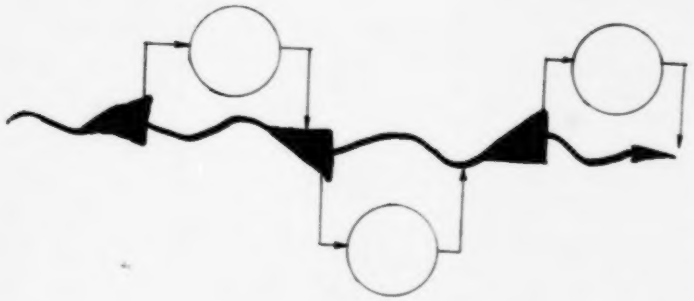
TABLE 11 : INDUSTRIAL REUSE PROJECT, BENONI: COMPARISON OF WATER PRESENTLY IN USE WITH RECLAIMED WATER

CHARACTERISTIC	UNITS	CURRENT MUNICIPAL	RECLAIMED WATER
Approximate price	c/m^3	22,7	12
Turbidity	(NTU)	1,2	0,4
Colour	(PCU or Hazen)	7	54
Suspended Solids	(mg/ℓ)	0	0,1
Settleable Solids	(mℓ/ℓ)	0	0
Total Dissolved Solids	(mg/ℓ)	385	730
pH		8,4	7,0
Alkalinity (as CacO$_3$)	(mg/ℓ)	100	11
Hardness (as CaCO$_3$)	(mg/ℓ)	200	202
Calcium (as Ca)	(mg/ℓ)	47	53
Magnesium (as Mg)	(mg/ℓ)	13,4	24
Free and Saline Ammonia	(mg/ℓ)	0,1	1,4
Oxygen Absorbed	(mg/ℓ)	2,5	5,5
Total Phosphate (as P)	(mg/ℓ)	0,2	NA
Ortho Phosphate (as P)	(mg/ℓ)	NA	$<$0,2
Chlorides (as Cℓ)	(mg/ℓ)	30	175
Total plate count	(per mℓ)	22	12
Total coliforms	(per 100 mℓ)	0	0
E-Coli	(per 100 mℓ)	0	0

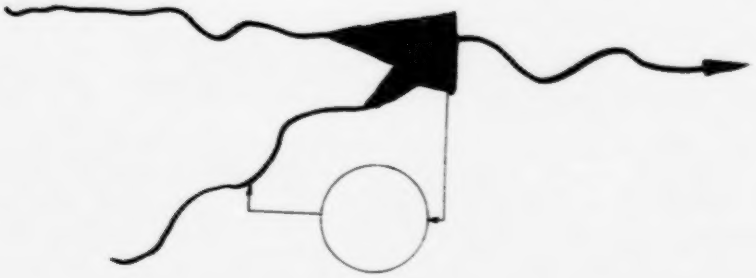
TABLE 12 : ANNUAL POINT SOURCE CONTRIBUTIONS OF FLOW VOLUME AND SALT LOAD TO THE VAAL VARRAGE SYSTEM 1977/78 (after WRC(34))

SOURCE OF EFFLUENT	FLOW VOLUME		SALT LOAD		AVE. SALT CONC.
	($10^6 m^3$)	PERCENT OF TOTAL	(10^3 t)	PERCENT OF TOTAL	(mg/ℓ)
MINES AND ASSOCIATED INDUSTRIES	50	18	137	60	2 740
INDUSTRIES	24	9	24	11	1 000
MUNICIPALITIES	200	73	67	29	335
TOTAL	274	100	228*	100	832

* NON-POINT SOURCES IN THE CATCHMENT CONTRIBUTE A FURTHER 340 000 t per annum of SALT.



(a) COVERT REUSE IN SERIES



(b) COVERT REUSE IN SEMI-CLOSED LOOP

FIGURE 1 : BASIC CONFIGURATIONS OF COVERT REUSE

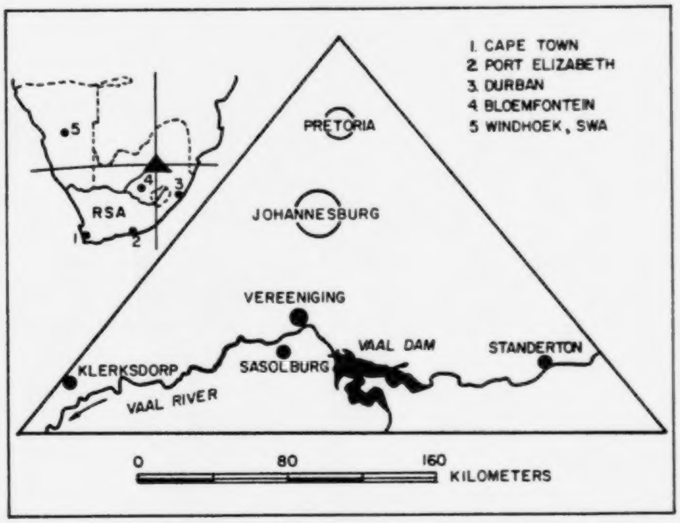

1. CAPE TOWN
2. PORT ELIZABETH
3. DURBAN
4. BLOEMFONTEIN
5. WINDHOEK, SWA
RSA
1
2
3
4
5
PRETORIA
JOHANNESBURG
VEREENIGING
VAAL DAM
STANDERTON
KLERKSDORP
SASOLBURG
VAAL RIVER
0
80
160
KILOMETERS

FIGURE 2: PRETORIA - WITWATERSRAND VEREENIGING - SASOLBURG COMPLEX(27)

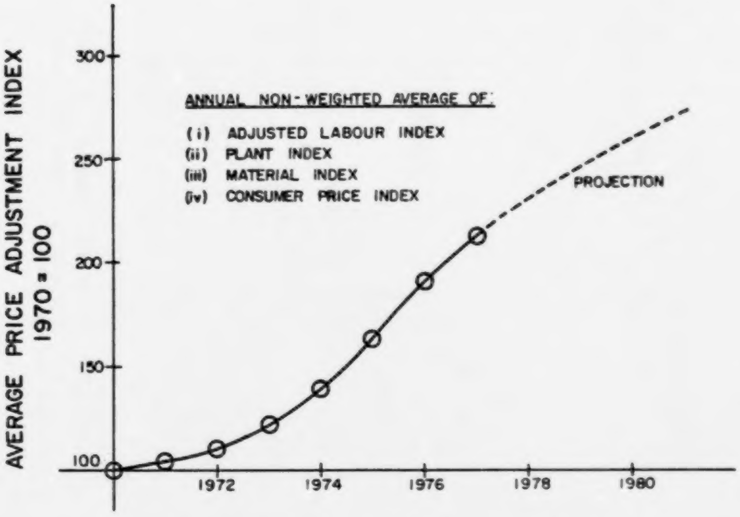


FIGURE 7: INDICES IN SOUTH AFRICAN CONSTRUCTION INDUSTRY
(SIMPLIFIED FROM REPORT P 27/1113(32))

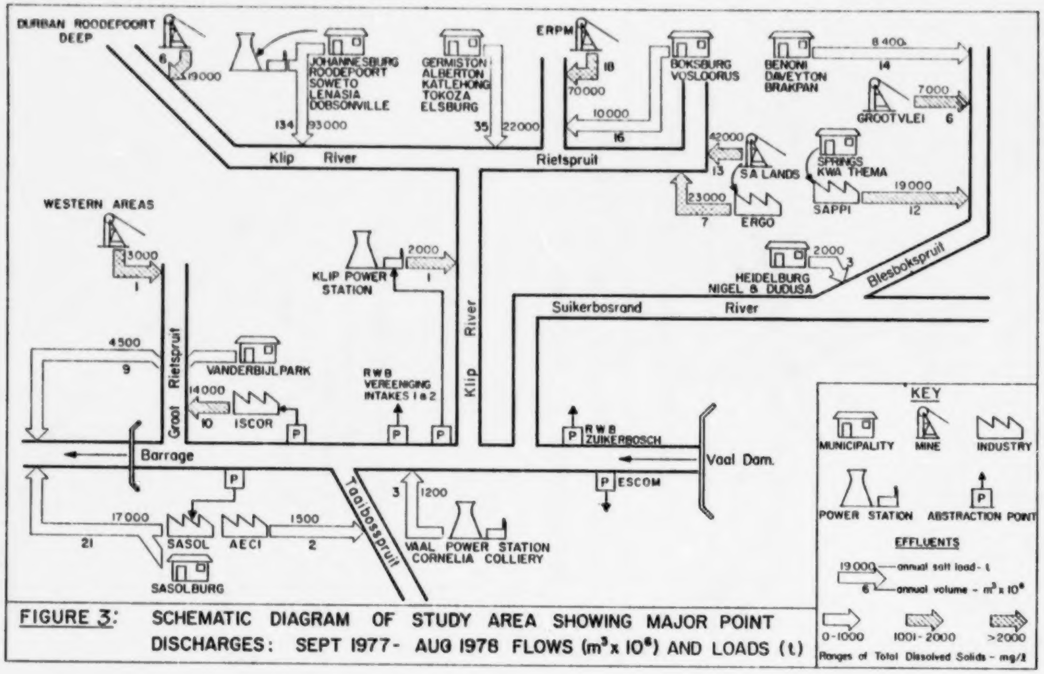

DURBAN ROODEPOORT DEEP
6
19000
JOHANNESBURG
ROODEPOORT
SOWETO
LENASIA
DOBSONVILLE
134
93000
GERMISTON
ALBERTON
KATLEHONG
TOKOZA
ELSBURG
35
22000
ERPM
18
70000
BOKSBURG
VOSLOORUS
10000
16
BENONI
DAVEYTON
BRAKPAN
8400
14
GROOTVLEI
7000
6
Klip River
Rietspruit
42000
13
SA LANDS
SPRINGS
KWA THEMA
23000
7
ERGO
SAPPI
19000
12
WESTERN AREAS
3000
1
KLIP POWER STATION
2000
1
HEIDELBURG
NIGEL & DUDUSA
2000
3
Blesbokspruit
Suikerbosrand River
4500
9
Groot Rietspruit
VANDERBIJLPARK
14000
10
ISCOR
P
RWB VEREENIGING INTAKES 1 & 2
Klip River
RWB ZUIKERBOSCH
Vaal Dam.
Barrage
ESCOM
3
1200
17000
21
SASOL
AECI
1500
2
Taaibosspruit
VAAL POWER STATION
CORNELIA COLLIERY
SASOLBURG
KEY
MUNICIPALITY
MINE
INDUSTRY
POWER STATION
ABSTRACTION POINT
EFFLUENTS
19000 — annual salt load - t
6 — annual volume - m³ x 10⁶
0-1000
1001-2000
>2000
Ranges of Total Dissolved Solids - mg/ℓ

FIGURE 3: SCHEMATIC DIAGRAM OF STUDY AREA SHOWING MAJOR POINT DISCHARGES: SEPT 1977 - AUG 1978 FLOWS ($m^3 \times 10^6$) AND LOADS (t)

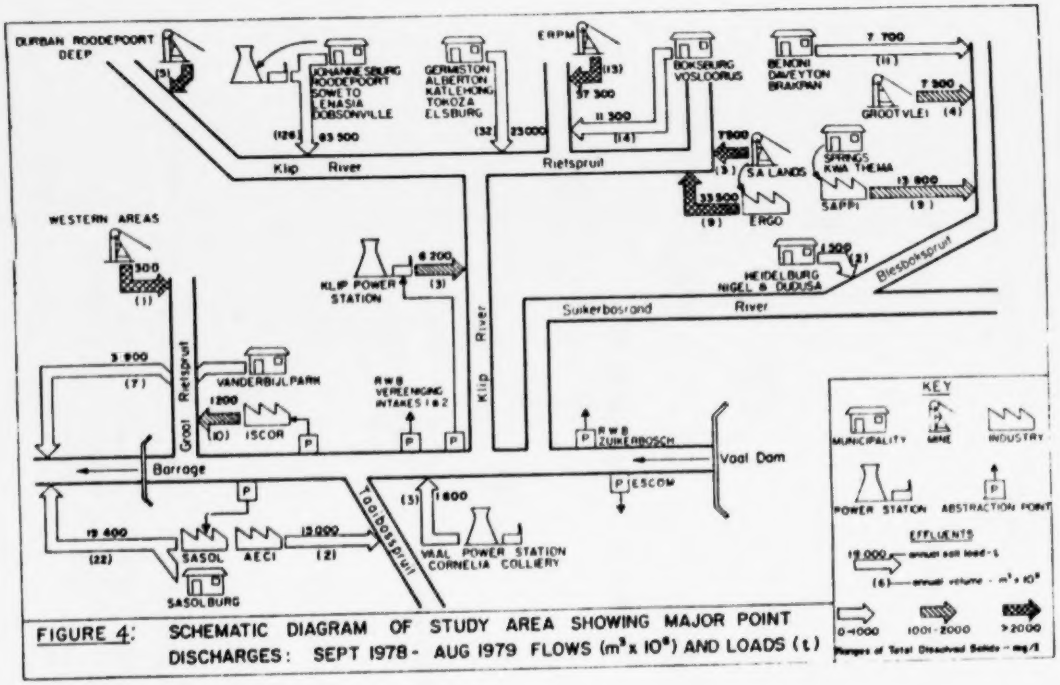
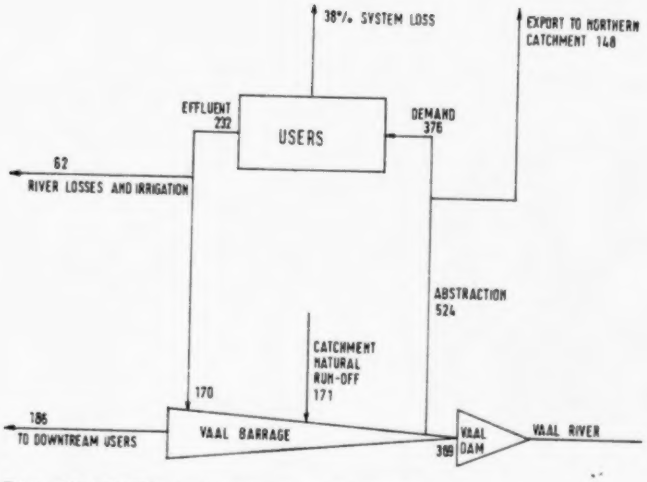
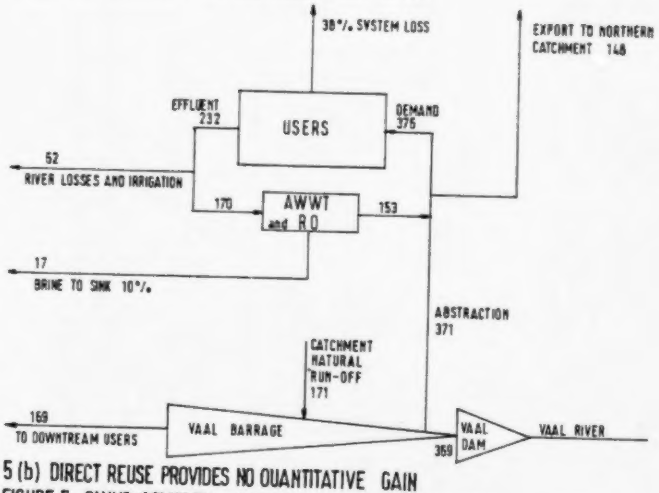

DURBAN ROODEPOORT DEEP
(5)
JOHANNESBURG
ROODEPOORT
SOWETO
LENASIA
DOBSONVILLE
(126)
83 500
GERMISTON
ALBERTON
KATLEHONG
TOKOZA
ELSBURG
(32)
23000
ERPM
(13)
37 300
BOKSBURG
VOSLOORUS
11 300
(14)
BENONI
DAVEYTON
BRAKPAN
7 700
(11)
GROOTVLEI
7 300
(4)
7900
(3)
SA LANDS
SPRINGS
KWA THEMA
33 300
(9)
ERGO
SAPPI
13 800
(9)
HEIDELBURG
NIGEL & DUDUSA
1 200
(2)
Blesbokspruit
Klip River
Rietspruit
WESTERN AREAS
300
(1)
KLIP POWER STATION
6 200
(3)
Suikerbosrand River
Klip River
3 900
(7)
Groot Rietspruit
VANDERBIJLPARK
1200
(10)
ISCOR
P
RWB
VEREENIGING
INTAKES 1 & 2
P
P
RWB
ZUIKERBOSCH
P
Vaal Dam
Barrage
P
ESCOM
P
19 400
(22)
SASOL
AECI
13 000
(2)
SASOLBURG
Taaibosspruit
(3)
1600
VAAL POWER STATION
CORNELIA COLLIERY
KEY
MUNICIPALITY
MINE
INDUSTRY
POWER STATION
ABSTRACTION POINT
EFFLUENTS
19 000 — annual salt load - t
(6) — annual volume - m³ x 10⁶
0-1000
1001-2000
>2000
Ranges of Total Dissolved Solids - mg/l

FIGURE 4: SCHEMATIC DIAGRAM OF STUDY AREA SHOWING MAJOR POINT DISCHARGES: SEPT 1978 - AUG 1979 FLOWS ($m^3 \times 10^6$) AND LOADS (t)

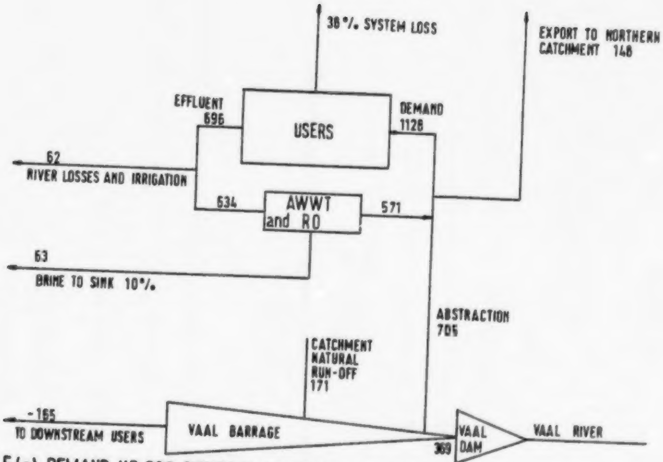

38°/. SYSTEM LOSS
EXPORT TO NORTHERN CATCHMENT 148
EFFLUENT 232
USERS
DEMAND 376
62
RIVER LOSSES AND IRRIGATION
ABSTRACTION 524
CATCHMENT NATURAL RUN-OFF 171
170
186
TO DOWNTREAM USERS
VAAL BARRAGE
369
VAAL DAM
VAAL RIVER

5 (a) THE SYSTEM AS IS SHOWING COVERT REUSE

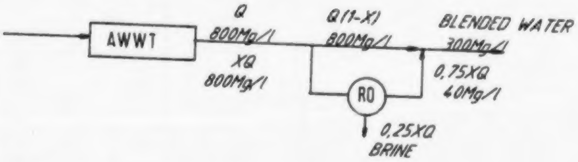

38°/. SYSTEM LOSS
EXPORT TO NORTHERN CATCHMENT 148
EFFLUENT 232
USERS
DEMAND 375
52
RIVER LOSSES AND IRRIGATION
170
AWWT and RO
153
17
BRINE TO SINK 10°/.
ABSTRACTION 371
CATCHMENT NATURAL RUN-OFF 171
169
TO DOWNTREAM USERS
VAAL BARRAGE
369
VAAL DAM
VAAL RIVER

5 (b) DIRECT REUSE PROVIDES NO QUANTITATIVE GAIN

FIGURE 5: PWVS COMPLEX VARIOUS REUSE CONFIGURATIONS
(All Quantities 10^6 M^3 per annum)


38 % SYSTEM LOSS
EXPORT TO NORTHERN CATCHMENT 148
EFFLUENT 696
USERS
DEMAND 1128
62
RIVER LOSSES AND IRRIGATION
634
AWWT and RO
571
63
BRINE TO SINK 10 %
ABSTRACTION 705
CATCHMENT NATURAL RUN-OFF 171
-165
TO DOWNSTREAM USERS
VAAL BARRAGE
369
VAAL DAM
VAAL RIVER

5(c) DEMAND UP 200 PERCENT ABSTRACTION UP 90 PERCENT
FIGURE 5: PWVS COMPLEX VARIOUS REUSE CONFIGURATIONS
(All Quantities 10^6 M^3 per annum)


AWWT
Q
800Mg/l
XQ
800Mg/l
Q(1-X)
800Mg/l
BLENDED WATER
300Mg/l
0,75XQ
40Mg/l
RO
0,25XQ
BRINE

Assume RO gives 75% recovery and 95% salt rejection
Start with flow =Q. TDS=800mg/l. Want blend of 300mg/l
Salt mass balance at mix, with X=fraction Q to RO:

$$800Q(1-X)+40(0,75XQ)=300Q(1-0,25X)$$

$$\underline{X=0,72}$$

CONCLUSION: 72% of flow must undergo RO treatment
18% of flow ends up as brine and must
be disposed of.

FIGURE 6: SIDE-STREAM DESALINATION OF AWWT PLANT EFFLUENT

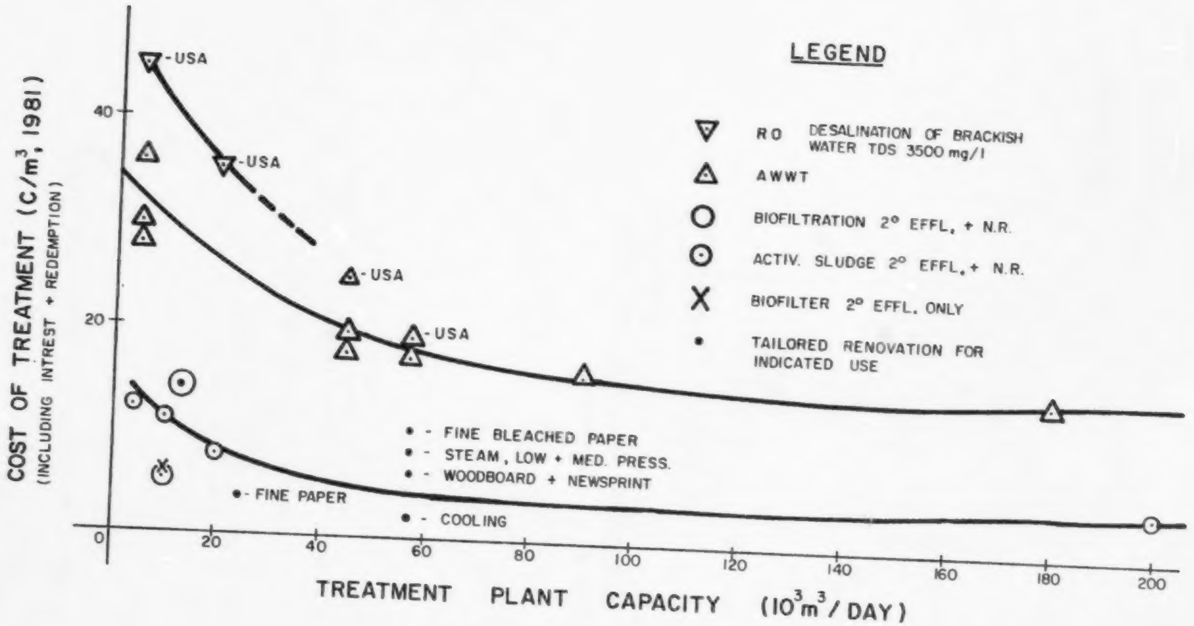


FIGURE 8: UNIT COST FOR VARIOUS TREATMENT PROCESSES ADJUSTED TO 1981 VALUE (AFTER (7)(9)(23)(29)(30)(31))

APPENDIX 1

Guide: Permissible utilisation and disposal of treated sewage effluent

Department of Health

Civitas Building
Private Bag X63
0001 Pretoria
Republic of South Africa

Telegrams
Health
Telephone
28-2851

CLASSIFICATION OF TREATED EFFLUENTS (SEWAGE PURIFICATION WORKS)

A

PS - PRIMARY AND SECONDARY TREATMENT - HUMUS TANK EFFLUENT

Conventional sewage purification according to accepted design criteria [*]. This includes screening and primary settling followed by biological purification such as the biological filterbed process or activated sludge process. Secondary treatment also includes the settling or clarification after biological or alternative purification methods.

PST - PRIMARY, SECONDARY AND TERTIARY TREATMENT

Final effluent complies with the GENERAL STANDARD[+], with the E. coli count relaxed to a maximum of 1 000 E. coli/100 ml

In addition to the above-mentioned primary and secondary or equivalent treatment one or more tertiary treatments, viz. land treatment, maturation pond, filtration, chlorination or other types of disinfection, etc., should be applied.

STD - PRIMARY, SECONDARY AND TERTIARY TREATMENT

(Compare with PST)

Final effluent complies with the GENERAL STANDARD[+] viz. inter alia NIL E. coli/100 ml

SP-STD - ADVANCED PURIFICATION

Final effluent complies with at least the SPECIAL STANDARD[+] and the quality compares favourably with that recommended for drinking water

In addition to the above-mentioned primary, secondary and tertiary treatment, advanced purification also includes special physico-chemical purification or other advanced techniques.

OD - OXIDATION POND SYSTEM

Final effluent contains a maximum of 1 000 E. coli/100 ml

The pond system should be designed according to a recognised standard[*] and operated in a nuisance-free manner. The combined retention time of the primary pond and approximately 4 secondary ponds should usually be at least 27 days. This system should drain into an irrigation dam of which the reserve storage capacity during dry weather conditions is at least 12 days. Unless sufficient space is available and the ponds are sufficiently remote from built-up areas, this system is not recommended for communities with a population exceeding 5 000.

Every oxidation pond system which is not able to deliver effluent of the above-mentioned quality should, for the purpose of this guide, be regarded on its merits as no more than equivalent to PS.

SEPTIC TANK EFFLUENT

(Primary settling and limited biological purification)

This effluent must undergo further secondary and tertiary or equivalent treatment before it may be utilised for the purposes indicated in this guide.

For the direct use or disposal, only nuisance-free land treatment or irrigation of fenced-in plantations will be permitted on its merits.

[+] GENERAL AND SPECIAL STANDARD

Quality requirements for purified sewage effluent as laid down by the Department of Water Affairs - see Government Notice R553 in Government Gazette Extraordinary of April 1962, and any amendments thereto. (E. coli = typical or faecal coli).

[*] DESIGN CRITERIA

Design criteria such as those set out in A Guide to the Design of Sewage Purification Works of the Institute of Water Pollution Control (I.W.P.C.), Southern African Branch (November 1973)

THE ABOVE CLASSIFICATION OF TREATED SEWAGE EFFLUENT TYPES IS USED IN THE FOLLOWING TABLES

DIRECTIONS FOR THE UTILISATION OF TREATED EFFLUENTS FOR IRRIGATION							B
	IRRIGATION OF	PS - PRIMARY AND SECONDARY	PST - PRIMARY, SECONDARY AND TERTIARY	STD - GENERAL STANDARD	SP-STD - ADVANCED PURIFICATION	OD - OXIDATION POND SYSTEM	
1.	*VEGETABLES AND CROPS CONSUMED RAW BY MAN (3 EXCLUDED) *LAWNS AT SWIMMING POOLS, NURSERY SCHOOLS, CHILDREN'S PLAYGROUNDS	*NOT PERMISSIBLE	*NOT PERMISSIBLE	*NOT PERMISSIBLE	*ANY TYPE OF IRRIGATION PERMISSIBLE	*NOT PERMISSIBLE	
2.	*CROPS FOR HUMAN CONSUMPTION WHICH ARE NOT EATEN RAW (VEGETABLES, FRUIT, SUGAR CANE) *CULTIVATION OF CUT FLOWERS (SEE ALSO 6)	*NOT PERMISSIBLE	*ANY TYPE OF IRRIGATION PERMISSIBLE *EFFECTIVE DRAINING AND DRYING BEFORE HARVESTING IS ESSENTIAL	*ANY TYPE OF IRRIGATION PERMISSIBLE	*ANY TYPE OF IRRIGATION PERMISSIBLE	*ANY TYPE OF IRRIGATION PERMISSIBLE ON ITS MERITS *EFFECTIVE DRAINING AND DRYING BEFORE HARVESTING IS ESSENTIAL	
3.	*FRUIT TREES AND VINEYARDS FOR THE CULTIVATION OF FRUIT WHICH IS EATEN RAW BY MAN (SEE 2 - FRUIT WHICH IS NOT EATEN RAW)	*NOT PERMISSIBLE	*FLOOD IRRIGATION PERMISSIBLE *DRIP AND MICRO-IRRIGATION PERMISSIBLE ON THEIR MERITS PROVIDED FRUITS ARE NOT DIRECTLY EXPOSED TO SPRAY *EFFECTIVE DRAINING AND DRYING BEFORE HARVESTING *FALLEN FRUIT IS UNSUITABLE FOR HUMAN CONSUMPTION	*ANY TYPE OF IRRIGATION PERMISSIBLE	*ANY TYPE OF IRRIGATION PERMISSIBLE	*FLOOD, DRIP AND MICRO-IRRIGATION PERMISSIBLE ON THEIR MERITS PROVIDED FRUITS ARE NOT DIRECTLY EXPOSED TO SPRAY *EFFECTIVE DRAINING AND DRYING BEFORE FRUITS ARE HARVESTED *FALLEN FRUIT IS UNSUITABLE FOR HUMAN CONSUMPTION	
4.	*GRAZING FOR CATTLE EXCLUDING MILK PRODUCING ANIMALS (SEE 5)	*NOT PERMISSIBLE	*ANY TYPE OF IRRIGATION PERMISSIBLE BUT NOT DURING GRAZING *GRAZING PERMISSIBLE ONLY AFTER EFFECTIVE DRAINING AND DRYING - NO POOLS *NOT PERMISSIBLE AS DRINKING WATER FOR ANIMALS	*ANY TYPE OF IRRIGATION PERMISSIBLE *PERMISSIBLE AS DRINKING WATER FOR ANIMALS	of *ANY TYPE OR IRRIGATION PERMISSIBLE *PERMISSIBLE AS DRINKING WATER FOR ANIMALS	*ANY TYPE OF IRRIGATION PERMISSIBLE BUT NOT DURING GRAZING *GRAZING PERMISSIBLE ONLY AFTER EFFECTIVE DRAINING AND DRYING - NO POOLS *NOT PERMISSIBLE AS DRINKING WATER FOR ANIMALS	

	IRRIGATION OF	PS - PRIMARY AND SECONDARY	PST - PRIMARY, SECONDARY AND TERTIARY	STD - GENERAL STANDARD	SP-STD - ADVANCED PURIFICATION	OD - OXIDATION POND SYSTEM
5.	*GRAZING FOR MILK PRODUCING ANIMALS (DEFINITION OF MILK - SECTION 1(XV) OF THE HEALTH ACT 1977 (ACT 63 OF 1977))	*NOT PERMISSIBLE	*NOT PERMISSIBLE	*ANY TYPE OF IRRIGATION PERMISSIBLE *PERMISSIBLE AS DRINKING WATER FOR ANIMALS	*ANY TYPE OF IRRIGATION PERMISSIBLE *PERMISSIBLE AS DRINKING WATER FOR ANIMALS	*NOT PERMISSIBLE
6.	*CROPS NOT FOR GRAZING, BUT UTILISED AS DRY FODDER *CROPS CULTIVATED FOR SEED PURPOSES ONLY *TREE PLANTATIONS *NURSERIES - CUT FLOWERS EXCLUDED (SEE 2) *ANY PARK OR SPORTSFIELD ONLY DURING DEVELOPMENT AND BEFORE OPENING THEREOF	*ANY TYPE OF IRRIGATION PERMISSIBLE ON ITS MERITS *NO OVER-IRRIGATION OR POOL FORMING *NO SMELL NUISANCE *PROPERLY FENCED *NO PUBLIC ALLOWED *NO MEAT ANIMALS, MILK PRODUCING ANIMALS OR POULTRY ALLOWED	*ANY TYPE OF IRRIGATION PERMISSIBLE (SEE ALSO 4 AND 5)	*ANY TYPE OF IRRIGATION PERMISSIBLE	*ANY TYPE OF IRRIGATION PERMISSIBLE	*ANY TYPE OF IRRIGATION PERMISSIBLE ON ITS MERITS (SEE ALSO 4 AND 5)
7.	*PARKS AND SPORTSFIELDS (SEE 6) *LAWNS AT SWIMMING POOL EXCLUDED (SEE 1)					
	(i) *PARKS, ONLY FOR BEAUTIFYING FLOWERBEDS, TRAFFIC ISLANDS ETC. - I.E. NOT A RECREATION AREA	*ONLY FLOOD IRRIGATION PERMISSIBLE *NO SPRINKLER IRRIGATION PERMISSIBLE *NO PUBLIC DURING IRRIGATION	*FLOOD IRRIGATION PERMISSIBLE *SPRINKLER IRRIGATION PERMISSIBLE ON ITS MERITS *NO PUBLIC DURING IRRIGATION	*ANY TYPE OF IRRIGATION PERMISSIBLE *NO PUBLIC DURING IRRIGATION	*ANY TYPE OF IRRIGATION PERMISSIBLE	*FLOOD IRRIGATION PERMISSIBLE *SPRINKLER IRRIGATION PERMISSIBLE ON ITS MERITS *NO PUBLIC DURING IRRIGATION
	(ii) *SPORTSFIELDS WHERE LIMITED CONTACT IS MADE WITH THE SURFACE, E.G. GOLF COURSES, CRICKET, HOCKEY AND SOCCER FIELDS, ETC.	*NOT PERMISSIBLE	*ANY TYPE OF IRRIGATION PERMISSIBLE *NO OVER-IRRIGATION AND NO POOL FORMING *NO PUBLIC OR PLAYERS DURING IRRIGATION *PUBLIC AND/OR PLAYERS ADMITTED ONLY AFTER EFFECTIVE DRAINING AND DRYING	*ANY TYPE OF IRRIGATION PERMISSIBLE *NO. OVER-IRRIGATION AND NO POOL FORMING	*ANY TYPE OF IRRIGATION PERMISSIBLE	*FLOOD IRRIGATION PERMISSIBLE *SPRINKLER IRRIGATION PERMISSIBLE ON ITS MERITS *NO OVER-IRRIGATION AND NO POOL FORMING *NO PUBLIC AND/OR PLAYERS DURING IRRIGATION *PUBLIC AND/OR PLAYERS ADMITTED ONLY AFTER EFFECTIVE DRAINING AND DRYING
				*NO PUBLIC AND/OR PLAYERS DURING IRRIGATION		

B (CONTINUED)

	IRRIGATION OF	PS - PRIMARY AND SECONDARY	PST - PRIMARY, SECONDARY AND TERTIARY	STD - GENERAL STANDARD	SP-STD - ADVANCED PURIFICATION	OD - OXIDATION POND SYSTEM
7.	(iii) *SPORTSFIELDS WHERE CONTACT IS OFTEN MADE WITH THE SURFACE, E.G. RUGBY FIELDS, ATHLETICS TRACKS, ETC. *SCHOOLGROUNDS, *PUBLIC PARKS - SPECIAL CHILDREN'S PLAYGROUNDS EXCLUDED (SEE 1)	*NOT PERMISSIBLE	*FLOOD IRRIGATION PERMISSIBLE *SPRINKLER IRRIGATION PERMISSIBLE ON ITS MERITS *NO OVER-IRRIGATION AND NO POOL FORMING *NO PUBLIC OR PLAYERS DURING IRRIGATION *PUBLIC AND/OR PLAYERS ADMITTED ONLY AFTER EFFECTIVE DRAINING AND DRYING	*ANY TYPE OF IRRIGATION PERMISSIBLE *NO OVER-IRRIGATION AND NO POOL FORMING	*ANY TYPE OF IRRIGATION PERMISSIBLE	*ONLY FLOOD IRRIGATION PERMISSIBLE *SPRINKLER IRRIGATION NOT PERMISSIBLE *NO OVER-IRRIGATION AND NO POOL FORMING *NO PUBLIC OR PLAYERS DURING IRRIGATION *PUBLIC AND/OR PLAYERS ADMITTED ONLY AFTER EFFECTIVE DRAINING AND DRYING
				*NO PUBLIC OR PLAYERS DURING IRRIGATION *PUBLIC AND/OR PLAYERS ADMITTED ONLY AFTER EFFECTIVE DRAINING AND DRYING		

IRRIGATION - GENERAL REMARKS AND PRECAUTIONS

(a) In order to obviate the irrigation system causing a nuisance in time, evidence must be produced that the type of soil and the size of the surface as well as the type of crop concerned are suitable for irrigation with the proposed quantity and quality of effluent.

(b) The piping used for effluent must be markedly different from the piping used for drinking water in respect of colour, type of material and construction. This precaution is necessary in order to obviate accidental cross-coupling of piping.

(c) In order to prevent persons from unwittingly drinking effluent water or washing with it, the taps, valves and sprayers of the irrigation system must be so designed that only authorised persons can open them or bring them into operation.

(d) Every water point where uninformed persons could possibly drink effluent water must be provided with a notice in clearly legible English, Afrikaans and appropriate Bantu languages, indicating that it is potentially dangerous to drink the water.

(e) The expression "after effective draining and drying" in the above-mentioned table means that the particular act may take place only when no pools or drops of effluent are evident in the irrigation area concerned.

(f) All possible precautions should be taken to ensure that no surface or underground water is contaminated by the irrigation water, especially where the latter does not comply with the General Standard. Excessive irrigation must therefore be avoided and the irrigation area protected against stormwater by means of suitable contours and screening walls.

(g) Sprinkler irrigation shall be permitted only if no spray is blown over to areas where such irrigation is forbidden. In this connection the quality of the effluent, the use of such adjoining area and its distance from the irrigation area must be taken into consideration before sprinkler irrigation is permitted.

DIRECTIVES FOR OTHER USES OF TREATED EFFLUENTS

	OTHER USES OF EFFLUENTS	PS - PRIMARY AND SECONDARY	PST - PRIMARY SECONDARY AND TERTIARY	STD - GENERAL STANDARD	SP-STD - ADVANCED PURIFICATION	OD - QXIDATION POND SYSTEM
1.	*INDUSTRIAL AND SUNDRY USES NOT MENTIONED IN THIS GUIDE	*PERMISSIBLE ON MERITS IN EXEPTIONAL CASES ONLY	*EACH CASE WILL BE TREATED ON ITS MERITS *THE EMPHASIS WILL BE ON THE E. COLI COUNT *IN GENERAL THE EFFLUENT MUST BE FREE FROM PARASITIC OVA, PATHOGENIC ORGANISMS, TOXIC SUBSTANCES, ETC.			*PERMISSIBLE ON MERITS IN EXCEPTIONAL CASES ONLY
2.	*FOOD INDUSTRY (ALSO COOLING WATER)	*NOT PERMISSIBLE	*NOT PERMISSIBLE	*NOT PERMISSIBLE	*NOT PERMISSIBLE	*NOT PERMISSIBLE
3.	*MINES AND INDUSTRIES: ORE TREATMENT, DUST CONTROL, ETC.	*PERMISSIBLE ON MERITS IN EXCEPTIONAL CASES ONLY	*PERMISSIBLE ON MERITS PROVIDED HUMAN CONTACT IS EXCLUDED	*PERMISSIBLE	*PERMISSIBLE	*PERMISSIBLE ON MERITS IN EXCEPTIONAL CASES ONLY
			*ALL TAPS AND WATER DRAW-OFF POINTS IN THE EFFLUENT DISTRIBUTION SYSTEM MUST BE PROVIDED WITH CLEARLY LEGIBLE NOTICES IN ENGLISH, AFRIKAANS AND APPROPRIATE BANTU LANGUAGES. INDICATING THAT THE WATER IS NOT SUITABLE FOR HUMAN CONSUMPTION			
4.	*HUMAN WASHING PURPOSES	*NOT PERMISSIBLE	*NOT PERMISSIBLE	*NOT PERMISSIBLE	*PERMISSIBLE ON MERITS *CLEARLY LEGIBLE NOTICES MUST BE DISPLAYED INDICATING THAT THE WATER IS NOT FIT FOR HUMAN CONSUMPTION OR FOOD PREPARATION	*NOT PERMISSIBLE
5.	*FLUSH TOILETS	*NOT PERMISSIBLE	*PERMISSIBLE ON MERITS *IN ORDER TO PREVENT THE USE OF EFFLUENT FOR UNAUTHORISED PURPOSES, NO OTHER DRAW-OFF BIBCOCKS SHALL BE AFFIXED TO EFFLUENT MAINS			*NOT PERMISSIBLE
6.	*DUST CONTROL ON ROADS	*NOT PERMISSIBLE	*PERMISSIBLE *EXCESSIVE SPRAYING AND POOL FORMING MUST BE AVOIDED *NO SURFACE OR UNDERGROUND WATER MAY BE POLLUTED		*PERMISSIBLE	*NOT PERMISSIBLE
			*NO SMELL NUISANCE MAY BE CREATED *ANY DIRECT HUMAN CONTACT WITH THE SPRAY MUST BE PREVENTED AS FAR AS IS PRACTICABLE. *STEPS MUST BE TAKEN TO ENSURE THAT NO EFFLUENT IS USED DIRECTLY OR INDIRECTLY FOR DOMESTIC PURPOSES *CONTAINERS USED FOR THE TRANSPORTATION OF EFFLUENT MUST NOT BE USED THEREAFTER FOR THE TRANSPORTATION OF DRINKING WATER BEFORE THEY HAVE BEEN EFFECTIVELY CLEANED AND DISINFECTED			
GENERAL REMARKS: IT IS COMPULSORY THAT THE NECESSARY PRECAUTIONARY MEASURES BE TAKEN WITH EACH OF THE ABOVE-MENTIONED USES IN ORDER TO PREVENT THE USE OF THE TREATED EFFLUENT FOR DRINKING OR DOMESTIC PURPOSES. IN ADDITION, IT IS ALSO COMPULSORY THAT THE MATERIAL AND/OR THE COLOUR OF THE EFFLUENT PIPELINE BE SUCH AS TO PREVENT ACCIDENTAL CROSS-COUPLING WITH DRINKING WATER PIPELINES. SEE ALSO (b) UNDER THE HEADING "IRRIGATION - GENERAL REMARKS AND PRECAUTIONS" ON PAGE 5						

METHODS OF DISPOSAL AND DISCHARGE OF TREATED EFFLUENTS					D
METHODS OF DISPOSAL AND DISCHARGE OF EFFLUENTS	PS - PRIMARY AND SECONDARY	PST - PRIMARY, SECONDARY AND TERTIARY	STD - GENERAL STANDARD	SP-STD - ADVANCED PURIFICATION	OD - OXIDATION POND SYSTEM
1. *DISCHARGE INTO RIVERS AND WATER COURSES, EXCLUDING ESTAURIES, DAMS AND LAGOONS - (SEE 2)	*NOT PERMISSIBLE	*PERMISSIBLE ON MERITS WITH DUE REGARD TO LOCAL CIRCUMSTANCES SUCH AS THE DILUTION FACTOR IN THE RIVER OR STREAM, RAINFALL, ETC. *THE PERMISSIBLITY OF DISCHARGE MUST BE DETERMINED WITH DUE REGARD TO THE USE OF THE RIVER WATER DOWNSTREAM *THE DISCHARGE POINT MUST BE DETERMINED WITH DUE REGARD TO THE POSITION OF WATER ABSTRACTION POINT(S) FOR DOMESTIC PURPOSES LOWER DOWN THE RIVER *THE EFFLUENT MUST CONTAIN NO HARMFUL SUBSTANCES IN CONCENTRATIONS DANGEROUS TO HEALTH	*PERMISSIBLE, PROVIDED THE EFFLUENT CONTAINS NO HARMFUL SUBSTANCES IN CONCENTRATIONS DANGEROUS TO HEALTH	*PERMISSIBLE	*NOT PERMISSIBLE
2. *DISCHARGE INTO ESTUARIES, DAMS, LAKES, LAGOONS OR OTHER MASSES OF WATER (SEA EXCLUDED - SEE 3)	*NOT PERMISSIBLE	*PERMISSIBLE ON MERITS IF REASONABLE ASSURANCE EXISTS THAT THE QUALITY AND VOLUME ARE SUCH AS NOT TO CAUSE NUISANCES OR HEALTH HAZARDS. *ONCE MIXED WITH THE EFFLUENT THE WATER MUST NOT BECOME LESS SUITABLE FOR DOMESTIC USE AND/OR RECREATION *THE EFFLUENT MUST CONTAIN NO HARMFUL SUBSTANCES IN CONCENTRATIONS DANGEROUS TO HEALTH	*PERMISSIBLE, PROVIDED THE EFFLUENT CONTAINS NO HARMFUL SUBSTANCES IN CONCENTRATIONS DANGEROUS TO HEALTH	*PERMISSIBLE	*NOT PERMISSIBLE

	METHODS OF DISPOSAL AND DISCHARGE OF EFFLUENTS	PS - PRIMARY AND SECONDARY	PST - PRIMARY, SECONDARY AND TERTIARY	STD - GENERAL STANDARD	SP-STD - ADVANCED PURIFICATION	OD - OXIDATION POND SYSTEM
3.	*DISCHARGE INTO THE SEA	*ONLY PERMISSIBLE BEYOND THE SURF ZONE *THE DISCHARGE POINT MUST BE DETERMINED WITH DUE REGARD TO THE QUALITY AND VOLUME OF EFFLUENT, THE SEA CURRENTS, THE DISTRIBUTION AND DILUTION OF EFFLUENT, AND THE PROXIMITY OF PRESENT AND FUTURE BATHING AREAS *NO COASTAL AREA MAY BE POLLUTED WITH EFFLUENTS CONTAINING SUBSTANCES WHICH ARE POTENTIALLY DANGEROUS OR HARMFUL TO HEALTH *THE DISCHARGE OF EFFLUENT MUST NOT CAUSE ANY NUISANCE OR HAVE ANY EFFECT ON MARINE LIFE WHICH MAY ADVERSELY AFFECT MAN DIRECTLY OR INDIRECTLY		*PERMISSIBLE *DISCHARGE INTO THE SURF ZONE MUST BE DETERMINED WITH DUE REGARD TO THE PROXIMITY OF PRESENT AND FUTURE BATHING AREAS AND THE EFFECT ON THE QUALITY OF SEA-WATER IN SUCH AREA	*PERMISSIBLE	*PERMISSIBLE ON MERITS AS FOR PS AND PST
	IN MOST CASES THE INFLUENCE OF THE ABOVE-MENTIONED DISCHARGES IS NOT DIRECTLY PREDICTABLE. IT WOULD THEREFORE USUALLY BE REQUIRED THAT THE NECESSARY INVESTIGATIONS BE MADE TO DETERMINE SUCH INFLUENCE WITH REASONABLE CERTAINTY.					

GENERAL DIRECTIONS AND PRECAUTIONARY MEASURES	E
(a) The sewage purification works must be efficiently operated by adequately trained personnel at all times and must, as far as is reasonably practicable, not be overloaded. (b) The person or authority in charge of the purification works must satisfy himself that the quality of the final effluent will at all times be in accordance with the directives as set out in this guide. (c) Regular control tests of representative final effluent samples must be made at least quarterly and records must be kept of such tests. (d) The person or authority in charge of the works must ensure that the quality of the final effluent and the use thereof comply with the directives set out in this guide - also when such effluent is utilised by another person or body. The supply and utilisation of effluent must be terminated if the directives set out in this guide are not complied with.	(e) A person or body using the final sewage effluent for a purpose set out in this guide, but not undertaking the purification himself, must satisfy himself that only permissible utilisation practices are maintained and must forthwith discontinue the use thereof should he become aware of any deviation from the directives contained in this guide. (f) Compliance with the requirements for the utilisation of purified sewage effluent as set out in this guide is the individual and joint responsibility of both the supplier and the user of the final effluent. (g) In the case of a use qualified in this guide as permissible on merit, it will be necessary for the relevant uses and methods of use to be thoroughly motivated and investigated. The majority of such cases, stricter supervision and control of the system as well as the quality of the effluent will be required in order to prevent the development of any nuisance or condition dangerous to health.

APPENDIX 2

CUT COSTS : USE RECLAIMED WATER!

Current quality standards imposed on domestic effluents are such that, with some additional treatment, it is possible to produce water for large-scale reuse in non-critical industrial processes.

The Town Council of Benoni is embarking on just such a project and acting on the advice of the C.S.I.R., is contemplating the construction of a 15 000 m³/day advanced wastewater purification plant. It intends extending the line currently supplying Dunswart, Afrox and Falchem with purified domestic effluent to other industries in Benoni and also to Boksburg East and adjacent industrial areas.

WHAT'S IN IT FOR YOUR INDUSTRY?

Should enough industrialists be interested (and there is every indication that they will be), an assured supply of reclaimed watter will be delivered to your property boundary at a pressure of 3,2 bar (45 lb./sq. in.) at approximately half the price you are currently paying for municipal water.

The attached table compares the quality of reclaimed water with that currently supplied to your industry via the municipal distribution system. (see Table 11 in text)

In general it can be said that the reclaimed water should be ideally suited for processes such as cooling, equipment and floor washing, etc. Use of this much cheaper water as boiler feed-water would have to be weighed up against possible additional demineralization costs. A further capital cost to your company would be the laying of a dual piping system in distinctly coloured pipes to prevent cross-connection with drinking water circuits.

ACTION REQUIRED :

Kindly give this matter your careful consideration and furnish the basic information called for on the attached form.

This project could be to your company's economic advantage and will most certainly pave the way to more efficient utilization of one of the country's most precious resources, WATER.

QUESTIONNAIRE

COMPANY NAME AND ______________________________
ADDRESS ______________________________
____
____

YOUR NAME ______________ PHONE NO. ____________

TYPE OF INDUSTRY ______________________________

ESTIMATED CURRENT WATER USE ______________ m^3/day.

ESTIMATE OF PROPORTION OF TOTAL WATER USED IN THE FOLLOWING PROCESSES: (Please tick those which could use reclaimed water)

	PERCENT	COULD USE RECL. WATER
COOLING		
FLOOR AND EQUIPMENT WASHING		
BOILER FEEDWATER		
OTHER (PLEASE SPECIFY) :		
______________		
______________		
______________		
______________		
______________		

ANY COMMENTS ON REASONS FOR ACCEPTANCE OR REJECTION OF RECLAIMED WATER WOULD BE VALUED.

PB82-223330

APPROPRIATE WATER RE-USE TECHNOLOGY FOR DEVELOPING COUNTRIES

Ben Z. Diamant

Professor of Environmental Engineering

Department of Water Resources
and Environmental Engineering
Ahmadu Bello University
Zaria - Nigeria

INTRODUCTION

National development programmes in many Third World countries have been concentrating in recent years on industrial promotion. Industrialization has always been regarded in the developing countries, as the most suitable remedy for the many chronicle set-backs prevailing there, such as poor balance of payments, growing dependency on imported commodities and soaring unemployment. Industrial development has been, therefore, largely encouraged in these countries, where it has inevitably caused sharp increases in the already existing urbanization trends, resulting in rapidly expanding townships, both in space and in population density. Shortages in major municipal services, such as water supply and waste disposal, have soon become acute and numerous Third World cities had to embark on new costly water supplies and in particular - central sewerage systems. Being usually regarded as development projects, most of these systems have been included in the National Development Programmes and were, hence, maintained by national - and quite often also - international funds.

Due to the existing acute shortage in local environmental engineering manpower in most developing countries, foreign consultants, mainly from the developed countries, had to be engaged for assuming the design and construction of these engineering projects. Though there is no doubt about the competence and sound professional background of the foreign consultants, the fact still remains, that many of them were lacking adequate knowledge on the environmental conditions that were existing in their countries of assignment. Many consultants had to depend, therefore, on experience achieved in their own developed countries and tried to apply it to the developing countries, with their entirely different environmental conditions.

One of the fields that has been mainly affected by this wrong approach, was - wastewater disposal. This paper will discuss this issue, point out its ill effects and make recommendations for more approariate waste disposal and water re-use technologies for developing countries.

ENVIRONMENTAL CONSIDERATIONS

Water supply and wastewater disposal are two interrelated environmental issues, classified among the most important components of the human environment. The industrial revolution in Europe in the 18-th century intensified the urgency of these two environmental problems. Since then they have been continuously tackled in the developed countries, until a satisfactory solution has been finally reached. Today, almost every person living in the developed countries, including those living in the rural areas, has access to safe drinking water and adequate waste disposal facilities.

On the other hand side, the relevant situation in the developing countries is, unfortunately, entirely reversed. There, an overwhelming majority of the population is not provided with safe water supplies and proper sanitation facilities. The situation is particularly grave in the rural areas, where most developing countries people live. The population distribution forms another distinct difference between the developed and the developing countries. Unlike the latter, most people in the developed countries live in urban areas. In West-Germany, for example, only 3.7 % of the 61.4 million people, lived in 1978 in communities of 1,000 people and less (West-German Statisitics, 1979). A demographic survey carried out in the developing countries has shown that not less than 72 % of the people were living in rural areas (WHO, 1973). In some typical developing parts of the world, like the African continent, the ratio rises to as high as 83 % (WHO, 1976).

The World Health Organisation has carried out, during the period 1970-1980, a global survey on Water Supply and Wastewater Disposal in the Developing Countries (WHO, 1976). An interim report on the Survey, released in 1976, has covered the period of the first half of the decade. Extreme differences in the provision of the two basic community services, were found between the urban and rural areas, with the former being far better off, in some cases up to 8 times. The findings of the survey were expressed in percentages of people provided with the two services in both, the urban and the rural zones, in 1970 and in 1975. Based of its interim findings, the report, further, established estimated targets for 1980. The following Table summarizes these findings, as well as, the estimated targets for 1980.

Table 1. Water Supply and Wastewater Disposal in the Developing Countries

Year	Percent of the Population served					
	Water supply			Wastewater disposal		
	Urban	Rural	Mean *	Urban	Rural	Mean *
1970	76	14	29.0	72	9	25.0
1975	77	22	37.4	75	14	28.8
1980	91	36	51.4	94	24	43.6

* The means were computed according to the 28/72 ratio of the rural/urban population distribution.

The WHO Survey's findings clearly pointed out the severe environmental conditions in the rural areas, in comparison to the conditions in the urban areas of the developing countries. The findings showed that in 1970 only 1 out of 7 rural inhabitants had access to safe drinking water and only 1 out of 11 - to proper waste disposal facilities. A slight improvement has been noticed in 1975 when the relevant ratioes have increased to 1:5 and 1:7 respectively. The Survey's estimated targets for 1980 were based on previous experienced improvements and on an expected investment in the rural areas of the developing countries, of not less than US $ 14,500,000,000 (in 1975 prices). Accordingly, it has been anticipated that by 1980, "only" 2 out of 3 and 3 out of 4 rural people, would not have access to safe drinking water and sanitation facilities respectively. Unfortunately, even these humble expectations, have not, apparently come true. According to recently released figures, the water supply and sanitation situations in the rural areas in developing countries by the end of 1980, indicated a slight improvement in the provision of safe drinking water, from 22 % in 1975 - to 29 % (instead of the 36 % target) in 1980. As far as proper sanitation was concerned, the situation has even worsen, from 14 % of provision in 1975 to 13 % (instead of the 24 % target) in 1980 (World Water, 1981).

The deteriorating environmental conditions have had detrimental repercussions in the developing countries. Out of the 13.6 million children that died in the world in 1979, 13.1 million were from the developing countries. "Most of these deaths were caused by water-borne diseases and could have been, therefore, potentially prevented" (WHO, 1980). Figure 1 shows the state of drinking water supply in the rural areas of the developing countries during 1970-80.

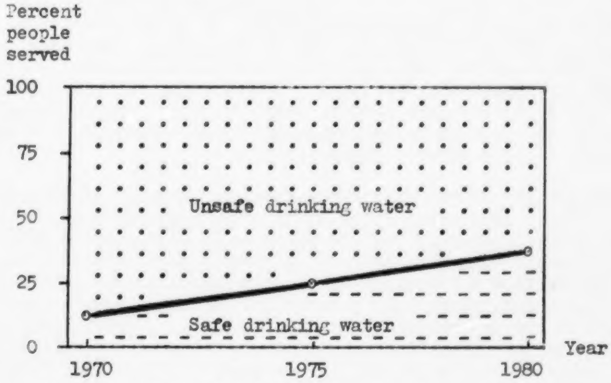


Figure 1. Rural Drinking Water Supply in the Developing Countries (1970-1980)

The above mentioned detailed discussion on the present state of water supply and waste disposal in the rural areas of the developing countries was essential for understanding the full impact of the wrongly practiced urban wastewater disposal, on the environmental health conditions in these rural areas.

URBAN WASTEWATER DISPOSAL

The conventional disposal of urban wastewater treatment plants effluents is usally carried out by means of dilution in natural bodies of water, such as rivers and lakes. The rate of such disposal has to be determined according to the biochemical load (B.O.D.) of the effluent and the volume and flow of the receiving body of water. Failing to observe these two factors might lead to the development of septic conditions in the natural body of water, destruction of aquatic life and creation of severe health hazards and sanitary nuisances. Inorder to prevent such set backs, most wastewatershave to pass a series of purification stages, to reduce their biochemical load to the level acceptable by the receiving water. Following disposal, the receiving water will enter a process known as self-purification, during which the organic contamination that entered with the effluent, will be oxidized and decomposed by the continuous reoxygenation of the natural body of water (Fair, 1971). Until this self-purification process is completed, the receiving water is considered to be contaminated and dangerous for consumption.

Water pollution

It is quite often assumed that wastewater disposal by means of dilution in natural bodies of water, can be considered safe, as long as a reasonable rate of dissolved oxygen is left in the receiving water and as long as the aquatic life in water is not affected. This widely accepted attitude can be tolerated in the developed countries, where almost allpeople including those living in the rural areas, have accessto safe drinking water and sanitation facilities and where, practically, nobody drinks water from surface raw resources. But in the developing countries, where more than 2 out of 3 rural people consume water from raw surface sources (World Water, 1981), wastewater disposal by means of dilution in natural water, can not be accepted at all. In the present environmental health circumstances in the developing countries, no wastewater whatsoever, whether raw, partially treated or fully treated, should be allowed to come in contact with any natural body of water. The following example indicates the tremendous pollution impact of wastewater effluent on a receiving body of water (Diamant, 1979) :

100 millilitres of raw domestic wastewater contain approximately 2,000,000,000 intestinal germs known as *E. coli* bacteria. *E. coli* is relatively not harmful, but its presence in water serves as an indicator for pathogenic contamination. An effective wastewater treatment plant usually provides a reduction of 90-95 percent, in the original contamination potential, along full primary and secondary purification stages. But let us assume the existence of a theoretical treatment plant that can provide, not only 95 percent, but 99.99 percent purification. Such plant never exists, ofcourse, in practice. The effluent of this theoretical plant will,hence,contain *E. coli* bacteria at a rate of -

$$(100 - 99.99) \times 2x10^9 = 200,000 / 100 \text{ ml}$$

When this effluent is diluted in a river having a very favourable dilution rate of 10 : 1 , then 100 ml of the receiving water will contain now only 20,000 *E. coli* bacteria. Let us further assume a reduction of 50 percent in this rate of contamination, due to the above-mentioned self-purification process that takes place in the river (Fair, 1971), so that its water will contain now 10,000 E. coli bacteria in 100 ml of diluting water. The consensus on the upper permissible concentration of *E. coli* bacteria in rural water supplies is 10 / 100 ml, which means that the extremely purified wastewater effluent, diluted in excellent conditions, still contains E. coli concentrations at a rate which is 1,000 times higher than the recommended upper permissible limit. It is quite clear, hence, that wastewater disposal by means of dilution in natural bodies of water, can not be acceptable in the developing countries, where most people obtain their water supply directly from raw sources.

Municipal effluents

Most large cities in the developed, as well as in the developing countries, are located near natural water sources, in most cases - large rivers. These rivers flow through the cities, where they first provide the water supply and then dilute the wastewater for disposal purposes. After a short while, the contaminated rivers reach the rural areas, where in the case of developing countries, most people drink the water from the river in its raw state. This forms one of the major reasons for the high morbidity and mortality rates in these countries. Unfortunately, the human senses are not sharp enough to detect dangerous contamination levels in water, by means of smell or sight. Most treated municipal effluents are normally highly oxidized with a clear appearance and no smell traces, which hide their dangerous contamination content. In view of such disturbing circumstances, it might be advantageous to let the raw wastewater to enter the river, rather than the treated and purifies one, so as to enable the innocent rural people to detect with their senses the dangerous smell and sight and refrain from drinking the water (Diamant, 1978).

Foreign consultants involved in the design and construction of central sewerage systems in the developing countries, are quite often not sufficiently aware of the real environmental health conditions in these countries. They simply adopt, therefore, and apply in their designs the wastewater disposal methods practiced in their developed countries, where environmental conditions are entirely different. Such applications have been observed quite often in many developing countries in recent years. A striking example is the newly designed city of Abuja in Nigeria, which is due to replace Lagos as the Federal Capital. The town-planning plans included, ofcourse, a central sewerage system, but the disposal of the treated wastewater has been designed to be carried out by means of dilution in a natural body of water. The writer has expressed his views on the matter, with the hope that the designed method of disposal will be altered.

The most appropriate alternative to the dilution disposal method, is the land application disposal method, which practices the use of the wastewater for agricultural irrigation purposes.

LAND APPLICATION

The land application wastewater disposal method has a double advantage. It prevents the contamination of natural water courses and at the same time it exerts productive use of the wastewater and its organic fertilizer content, otherwise lost in the dilution disposal method (Bouwer, 1978). Following the increased use of - and the growing need for - water resources in recent years, water has become a scarce and valuable commodity. In some countries where water shortages have reached acute stages, like in Israel, for example, wastewater has been recognised and considered as a component of the national water resource and almost all of it is re-used, mainly for agricultural irrigation purposes (Livharer, 1976). Though irrgation with wastewater was found to cause certain environmental problems such as soil salinity and heavy metals poisoning effects (Diamant, 1979a), experience has shown that under equal conditions, irrigation with wastewater had produced better yield and quality than irrigation with freshwater. Experiments carried out in Ahmadu Bello University in Zaria, Nigeria, with pairs of equal plots planted with the same crop, one irrigated with wastewater and the other with freshwater, have shown that the former irrigation resulted in better quality and higher yields of crop (Amadi, 1973. Mafara, 1979).

The decision on the kind of crop to be irrigated with wastewater, lies with the competent agronomist that will select the crop according to local conditions, such as soil, climate and marketing, but in line with environmental requirements. This paper will discuss only these requirements and make recommendations for the appropriate wastewater disposal by means of agricultural irrigation. Various crateria have been worked out and recommended in this respect (Pound, 1973), but one major principle must always be observed in practicing this disposal method - the wastewater disposal should, as a rule, have the priority on the agricultural consideration or any other relevant aspects. For example, the wastewater must be accepted in the farm in dry days, as well as, in wet ones, when excess watering might affect the crop. To minimize such effects, larger than usual operational reservoirs should be built in the farm to store the wastewater effluent during very rainy days. As a rule, under no circumstances should wastewater by-pass the cropland and flow directly into natural bodies of water.

Due to the hazardous nature of the wastewater used for irrigation, certain limitations and precautions have to be regarded while operating this disposal method. These are normally related to the land requirements, the irrigation method, the raised crop and to the maintenance and management of the wastewater irrigated farm.

Land requirements

The available land for irrigation is, as a matter of fact, almost the only alternative to stream pollution. The design of the central sewerage system must include, therefore, not only recommendations for providing an adequate area for irrigation, but also measures to preserve this land for its specified purpose, by means of including it in the town-planning plan according to its designation, so that it should not be used for any other purpose. The required land will depend on the availalbe quantities of wastewater, as well as, on the type of the soil and on the water consumption of the raised crop. However, as a genral guide the required land can be estimated at a rate of 1 hectare for every 50 m^3 per day of available wastewater. The available wastewater has to be estimated according to future needs during a period of 15-20 years ahead.

Irrigation method

Irrigation with wastewater has to be performed only by means of surface application. Sprinkler irrigation might have certain important advantages on surface irrigation that include the access to elevated areas where the latter can not reach, the saving of the costly land leveling operatios and the prevention of forming isolated bodies of water that encourage mosquito and snail breeding (Diamant, 1980). But the sprinklers might spray in the air contaminated droplets of wastewater and should be, therefore, rejected in favour of surface irrigation.

Crop

Due to the health hazard contained in wastewater, non edible, industrial crops should be preferred on edible ones, when raised on cropland irrigated with wastewater. Among the former, should be preferred crops that require high water rates, such as eucalyptus trees. It should be noted that in the long run, the profits yielded by non edible crops, in the form of timber, for example, are higher than those yielded by edible crops. If, however, edible crops are to be raised, they should be confined to types that require cooking prior to consumption, such as potatoes or egg-plants, but never lettuce or tomatoes. The agronomist will have to make the final decision on the type of crop to be raised, provided the above-mentioned environmental precautions are adequately observed.

Maintenance

The maintenance of the wastewater-irrigated farm, must include special features related to the prevention of health hazards during the normal operation of the farm, such as piping identification, fencing and personal care.

Piping. All exposed sectionsof the piping network, carrying wastewater, must be painted in red colour, to indicate the dangerous nature of the content. Certain treated wastewater, in particular the effluent of maturation ponds in the wastewater stabilization ponds system, appears as clear and innocent as freshwater and might be mistakingly regarded as potable water. The dangerous nature of this clear wastewater has to be emphasized by its red painted piping.

Fencing. The whole area irrigated with wastewater has to be fenced inorder to prevent passers-by, in particular children, from entering the hazardous place. Signs in red letters should be attached to the fence, indicating the nature of the farm. It should be pointed out that non-edible crops do not usually attract passers-by. This can be considered as another reason why non edible crops should be preferred, in this respect, on edible ones. Although, under normal operational conditions, sanitary nuisances,such as obnoxous smells,are not expected to occur in the farm, such a possibility can not be overruled. The site for the farm should be, therefore, located as far as possible from the nearest residential zone. A thick line of tall trees should be planted along the fence facing this zone, to prevent sight and reduce the movement of smell-carrying winds.

Personal care. The employees of the wastewater irrigated farm must be adequately oriented on the special nature of their work. They should be provided with rubber boots,to be worn during working hours. Safe drinking water supply should be provided to the farm, as well as, showers. The employees should be requested to take a shower before leaving the farm. All employees must pass periodic medical examinations, to detect and prevent possible ill-effects.

Management

The various restrictions involved in the running of a wastewater irrigated farm, require intensive and constant supervision, which can not always be rpvided by the local authority respeonsible for the farm. It is, therefore, recommended that the local authority itself, rather than private farming enterprises, should operate the farm. Though the latter are believed to be more efficient than public bodies, they are nevertheless mainly motivated by the profit aspect, for which the environmental cause might be, probably, sacrificed. The local authority is likely to adopt more readily the important principle of running the wastewater-irrigated farm that the wastewater disposal has the priority on the agricultural interest. Furthermore, unlike private farmers, the local authority can afford waiting the long time required for raising safe non-edible crops like timber, instead of, say, vegetables. The local authority should be, therefore, directly responsible for the running of the farm and this should be clearly mentioned while allocating the necessary land for the farm and reserving it, as such, in the town-planning plan.

FISH PONDS

Most people living in the developing countries are affected by chronicle protein defficient food. Fish, which is one of the major sources of protein food, can be successfully raised in ponds containing a mixture of treated wastewater and freshwater. Large scale fish farming of this kind has been successfully developed in countries like India and Israel, where fish were partially fed on the organic matter contained in the wastewater.

It should be noted that the food value of fish produced in this method, exceeds the value of crops that could be raised on the same land (Babbitt, 1958). Furthermore, the effluent of the fish ponds can still be used for irrigation purposes, accomplishing, hence, the appropriate wastewater disposal technology. Certain precautions must, however, be observed when practicing fish raising in diluted treated wastewater. The minimum rate of dissolved oxygen in the ponds must not drop below 4 mg/l (Babbitt, 1958). When the collected wastewater contains wastes from industrial sources, care must be taken to prevent harmful chemical substances from entering the sewerage system and reaching apparently the fish ponds, where fish poisoning can be affected. This risk can, however, be controlled by imposing pretreatment requirements on the relevant industries. The pretreatment that has to be performed within the plant, is meant to remove - most likely by chemical precipitation - the harmful substances from the plant's wastewater, before it is released in the municipal sewer (EPA, 1975). This has to be supported by adequate legislation and the design of the central sewerage system should include suggestions and recommendations in this respect.

SUMMARY

Intensive industrial development followed by increased urbanization trends, have urged, in many Third World countries, the need for central sewerage systems in the over-crowded cities. Most of these systems have mistakingly adopted the wastewater disposal method by means of dilution in natural bodies of water, according to established practices in the developed countries. But unlike the latter, most people in the developing countries, in particular those living in the rural areas, drink raw water from unsafe surface sources. The disposal of wastewater by means of dilution in water courses, must be completely abolished in these countries and be replcaed by the far more suitable land application method. Irrigation with wastewater has, though, certain limitations related to the type of the raised crop, the method of irrigation and to the maintenance and management of the wastewater-irrigated farm. Fish raising ponds can be incorporated in the land application method.

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MEXICO CITY'S MASTER PLAN FOR REUSE

Gastón Mendoza Gamez
Head
Development Unit of Water Works Directorate of Mexico City

Francisco Flores Herrera
Project Leader of the Master Program of Treatment and Reuse
Development Unit of Water Works Directorate of Mexico City
San Antonio Abad No.231- 5°Piso
Mexico 068000, D.F. Mexico

1. INTRODUCTION

In the southern extreme of the Mexican Tableland at 2 240 m. above sea level, we found a depression known with the name of "Valley of Mexico". It is an endorreic closed basin, the shape seems like an elipse, with - its major axis, from NE to SW, of about 110 Km and the minor, from E to W, measures about 80 Km.

The area of the valley is close to 9 600 Km^2, and includes the old tributary basins of the Apan, Tecocomulco and Tochac lakes, incorporated - to the basin by recent works.

The basin is placed in the southern part of the central tableland between 19°03'53" and 20°11'09" north of latitude and 98°11'53" and 99°30' 24" west of longitude.

Figure 1 shows the federal entities that have jurisdiction on the basin. Concerning to the Federal District, all his surface is in the basin, except the part of Milpa Alta and South Western of Magdalena Contreras and Villa Obregon Delegations.

The history of Mexico City is very closely related to the characteristics of the Valley of Mexico. Since the times of Tenochtitlan, the governors of the City had built great hydraulic works to alleviate situations in-which,due to either excess or lack of water, there were alternatively -- floods and epidemics or droughts and famine.

In the modern city the majority of the population has satisfied its needs for drinking water, the productive activities have had enough water to support their development and during the last ten decades the city has-not suffered any catastrophic flooding.

However, in spite of the fact that many works have been operating properly for over 20 years, the shortage of resources has caused delays in -- maintenance for the existing installations which, together with an accelerated population increase, has produce several water supply and drainage problems.

By the end of the 40s, the water available in the Valley of Mexico, was insufficient and it became necessary to bring additional supplies from - the River Lerma Catchment Basin. In the near future it will be necessary to import water from sources which are both further away and at lower altitudes, with the higher costs this entails.

This, together with the undesirable effects of aquifers over exploitation and the inadequate land use and management, have made more efficient water use an imperative, along with the need for greater resources to be allocated to maintain the hydraulic installations, the improvement of water and land management procedures and better organization in order to - provide for the City's present and future development. For this reason- an integral planning system was designed which includes all the hydraulic system components and their interactions with other systems which - allows action to be taken quickly such as the deep drainage system, while still taking into account the short and long term needs.

Starting with the problems encountered in the urban and hydraulic systems some sub-programs were defined to be tackled by the present administration, complemented by a more general view to the year 2000.

In the beginning of 1980, the first version of the Hydraulic Plan for - the Federal District was finished, evaluated and reviewed in order to produce a second version of which a "resume" is presented in this paper, emphasizing those aspects related to treatment and reuse.

2. THE PROBLEM

2.1 Historical background

As already stated Mexico City's hydraulic works have been the response since pre-hispanic times to problems produced by flooding and scarcity of water. Table 1 shows the efforts which those works represent.

2.2. Urban and hydraulic framework

The Federal District (FD), occupies about 15% of the Valley of Mexico's total area of 9 600 km^2, which constitutes a closed catchment where most of the rain concentrates from July to September.

From the mean annual precipitation equivalent to 213 m^3/s (figure 2), an estimated 171 m^3/s is evapo-transpired and therefore not susceptible to use, 23 m^3/s recharge the aquifer and 19 m^3/s is surface runoff. From -- the last figure, 3 m^3/s are regulated for use and the rest are discharged through the Valley's drains in order to avoid flooding, since the surface runoff takes place in very short periods in which great volumes are concentrated.

At present, the Valley's users require 56 m^3/s of which 32.4 m^3/s are for domestic use, 11.3 m^3/s for industry, commerce and services, 4 m^3/s for public and recreational uses and 8.3 m^3/s for agriculture. In order to satisfy this demand some 11 m^3/s are imported from the over-exploited aquifers of the River Lerma's catchment basin.

From the aquifers ofthe Valley which are also over-exploited (40 m^3/s -- are extracted), 23 m^3/s of which come from infiltration and 17 m^3/s from the volume stored for centuries. In order to complete the required volume some 3 m^3/s of regulated surface runoff and 2 m^3/s of treated wastewater are used, figure 3.

As a result of using the aforementioned volumes, 40 m^3/s of wastewater - are produced, of which approximately 8 m^3/s are used to irrigate 18 000 Ha. in the Valley of Mexico and the rest for 56 000 Ha. in the Valley - of Tula. Wastewater expelled from the urban areas represents practically a constant discharge throughout the year, which can be conducted through piping of a relatively small diameter and the existing canals. However, 16 m^3/s from precipitation produced by a few short storms through the year generates instant runoff, peaking at 250 m^3/s in the drainage outflows of Mexico City. This has obligated the authorities to construct a number of large interceptors and other majors works such as the deep drainage system to conduce out of the valley the excess water and protect the city from catastrophic floods.

The over-exploitation of the Mexico's Valley aquifers, uncontrolled urban growth and inadequate land management have produced, besides canal-clogging, land sinking which damages pipes, a reduction in infiltration and more and faster runoff all of which upset the efficiency of the drainage system. Likewise, uncontrolled wastewater discharges have already polluted local areas where water wells have been closed. Such discharges and solid waste deposits on the open river beds have also reduced environmental quality.

Furthermore, the Federal District is part of a great metropolitan area which surpasses political bounderies and, in spite of the existing coordination mechanisms, water supply distribution and tariff charging are not completely integrated in the Metropolitan Area of Mexico City.

2.3. The Federal District's hydraulic system

This hydraulic system includes drinking water supply, drainage, treatment and reuse. These sub-systems have responded well to the users needs but have problems due to inadequate maintenance, imcomplete infrastructure, poor measures of water quality and the increasing demand for services.

2.3.1. Drinking water system

From the 56 m^3/s which are used in the Valley, 38.2 m^3/s correspond to the FD, of which 28.1 come from its own sources including the Lerma River, and 10.1 are given "en bloque" by the Water Commission of the Valley of Mexico.

At present, the drinking water system,figure 4 has 282 Km of conduction lines with diameters of 0.5 to 3.2 m, 90 pumping stations, 540 Km of primary network piping with diameters of 50.8 cm to 1.83 m, 11 700 Km of secondary network with smaller diameters and 186 tanks for storage and regulation with an overall capacity of 1.5 million m^3; this infrastructure is for delivering water to users. In 1978, 1.2 millions inhabitants lacked an installed service, at the end of 1981, 99% of population will be cover with the service. The system has been adversely affected in some - areas by sinking of the subsoil and the age of the pipelines, both of - which increase the likelyhood of leaks.

2.3.2. Drainage system

The present drainage system has a primary network of collectors consisting of 1 176 Km of pipelines with diameters of 0.60 m to 2.5 m, fed by - 12 000 Km of sewers with smaller diameters (figure 5). The volumes of - water collected by the primary network are concentrated and removed to - the Tula Valley by means of 42 pumping plants and 14 storm tanks,through large conduits such as the Gran Canal del Desague, the Western Interceptor and the Rivers Churubusco, La Piedad, Consulado, Los Remedios and -- Tlalnepantla, and the National Canal, among others. The deep Drainage - System formed initially by a Central Main and the Central and Western Interceptors, only carries rain water and does not operate in the dry season.

In 1980, 2 millions inhabitants lacked a proper drainage system (table 4) The existing infrastructure has been rendered prematurely obsolete by the increase in the drained area and soil sinking which has caused difficulties in serving the low lying areas. Furthermore, a reduction in effi-- ciency has occurred due to interference with the urban installations and the depositing of rubbish and sludge. Sanitary problems have been extended and intensified by discharges into the open ditches.

At the end of 1981, the sewage system still will be incompleted.

2.3.3. Treatment and reuse system

At the present 8 system exist for the treatment and reuse of the wastewater, the process used is activated sludge and in one of them besides, advanced treatment. The total installed capacity is about 4.2 m^3/s, but actually only 1.8 m^3/s are treated due to maintenance troubles and because the demand is not constant during the year. The renovated water is used for irrigation of public gardens and for recreational lakes. The areas irrigated belong to Chapultepec and Aragon parks, the recreational lakes that use treated waters are in these parks too and other in Xochimilco.

The physical, chemical and biological (PCB) parameters measured in the treated waters include only 8 of the 22 parameters considered basic for the quality control. Figure 6 shows the location of the treatment plants and the tables 5, 6 and 7 show the characteristics, production, uses and quality control of each one of the installations. The problem of the reuse of the wastewater is presented in the table 8.

3. FORECAST

In order to analyze the development of the hydraulic system, the hypothesis was taken for demographic growth in the FD, like a descentralized City as prepared by the "Colegio de México", which estimates a population of 17 millions inhabitants for the year 2000 for FD and 28.6 millions for the Metropolitan Area (Figure 7).

On the basis of this hypothesis, the demand for water for the year 2000 will be 71 m^3/s (table 9). To go on over-exploiting the Valley of Mexico's aquifer would accelerate the destructive effects of sinking and it could lead to the extraction of fossil water of bad quality. Also in the Lerma Valley, due to over-exploitation and demands from the area itself, the amount of water available for Mexico City will be reduced. This situation, together with the population growth would compel the importation of water from other basins, even with the reduction of water use. Besides from the demand growth in the FD, the needs of other users would also increase and competition will grow between the Valley of Mexico and the exporting basins for an ever more costly and scarce commodity.

If the distribution of the city continues to extend over the higher part of the Valley it will be necessary to raise the water above the services in order to satisfy the demand.

The growing urbanization is generating greater volumes of faster flowing runoff into the drainage system.. This is particularly true in the -- western area of the city where the inclination of the land favours the concentration of runoff (table 10). Furthermore the sinking in the city, the interference with other urban services and the accumulation of sludge in the sewers result in a reduction of the system efficiency. The sinking in the south and east of the FD will continue and the present drainage system cannot drain this area. For the year 2000 the FD will produce wastewater at a rate of approximately 50 m^3/s.

Respect to the treatment and reuse system, the maintenance will be improved and rehabilitation will take place in order to avoid a total -- breakdown of the system. The technological development will be based in research and preparation of human resources that will work on regulations for the control of discharges to the drainage and on the control of quality of renovated waters. In this way, we will have:

In the short term (1982) (Table 11)

- 4.2 m^3/s of controlled treated waters
- To recover drinking water to be provided to population
- Control adverse effects to the human health and environment (principally the aquifer) by the growing volumes of wastewaters treated.

In the medium and long term (2000)

- Reduced volumes of potable water imported into the Valley of Mexico
- Reduced over-exploitation of the Valley's aquifer
- Improved planning for the management and control of the waters into the valley
- Qualified human resources for the management of the systems

4. HYDRAULIC PRINCIPLES

In order to deal with the problem, it was established the following -

principles for the hydraulic system (table 12):

- Efficient use of water, avoiding waste and leaks
- To reuse treated wastewater, taking into account its present use
- To intensify the conservation of water in the Valley of Mexico
- To import water in sufficient quantities to cover the deficiencies - left by the foregoing activities.

The efficient use of water has become imperative in the face of growing costs for new sources, it implies joint action on the part of the authorities and the users, for which the former should start technical-administrative measures which allow greater efficiency and lower costs, and the latter should acquire greater consciousness of the cost of the services provided and of the efforts required to provide them.

The use of treated wastewater within the Federal District is only beggining and does not relate to its true potential which, once relatively low costs have been established, would allow considerable volumes of -- drinking water to be free for domestic use.

The conservation of the quality and quantity of water in the Valley of Mexico implies the establishment of much more aggressive measures than- those traditionally adopted within a global strategy which take into account the general sanitation of rivers and basins, such as the construction of works for the regulation of floods, use of surface water and the recharging of aquifers. The sanitation of basins is of special importance, as without it there is always the risk of polluting the Valley's -- aquifers and so lossing a source of good quality water, which, even if- not over exploited, for the year 2000 will provide the Federal District with 20 m^3/s.

In short, the Hydraulic Program is a serie of actions allow the integral development of the Federal District's hydraulic system (figure 8), and - of its three main systems, potable water, drainage and reuse, attending duly to the interactions of the hydraulic system with the users and the- hydraulic system.

5. STRUCTURE OF THE WATER PROGRAM FOR TREATMENT AND REUSE

5.1. Objectives

- To make treated water a complementary source to provide water to the population, in the short and medium term for those uses that do not - require a PCB quality similar to potable water and in the long term - for domestic use, and recharging of the aquifer
- To reduce the over exploitation of groundwater
- To reduce the potential risk of pollution in the aquifer by using -- wastewater
- To increase the efficiency in the management of the water use, both - qualitatively and quantitatively
- To develop a methodology applicable to other reuse schemes in similar urban areas

5.2 Outline

- Taking full advantage of the installed capacity of the existing treatment plants
- Rehabilitation and preventive maintenance for the existing treatment - systems and those in construction process
- Gradual substitution in non domestic uses of potable water for treated water
- Contribution, in the long term, of treated water to provide potable - water for the population and the recharging of aquifers

5.3 Goals

Given the large volumes of wastewater generated in Mexico City, the possibilities of reuse, the potential market and the present technological conditions, it is possible to establish three goals for the implementation of the program which are:

ACTION		GOAL Consumption (m^3/s) partial	 total	Uses/application
Short term	Minimum	4.2	4.2	Irrigation of green areas, filling inlakes, and industry
Medium term	Medium	4.5	8.7	The foregoing plus agricultural irrigation
Long term	Maximum	No determined yet		The foregoing plus commercial and services uses. Recharging the aquifer and domestic use.

6. PROGRAM DEVELOPMENT

To reach the goals proposed in this Master Plan, but considering the limited information on technical, economical, social, institutional, public health and enviromental fields, besides the financial and public acceptance-public support, were estructured several basic studies shown in table 13, where is shown the description, objectives and the applications of the expected results; (figure 9) shows the interrelations of the forementioned studies. In the next paragraphs are described the principal results of the initiated studies which permit to structurate some schemes for the intensive and extensive use of renovated waters.

6.1 Demand of renovated waters

Table 14 presents the different uses of the potable water in the FD and a projection of the demand for the year 2000. It can be observed that actually more than 27% of the water (industrial, public and agricultural uses) can be substituted by renovated water from a secondary treatment. If the policies to supply renovated waters for the uses above mentioned continue, on the year 2000 the 17% of the demanded water for-that uses will be satisfied and depending of the technological advances and economical support will be possible to increment the reuse in other areas like commercial, aquifer recharge and possibly drinking uses.

6.2 PCB quality of wastewater

From the 50's there has been a growth in the industrial sectors in specific points of the country, specially in the Valley of Mexico, where - the industries, localizated in 17 zones, demand 4.8 m^3/s (80% of the total volume for the industrial uses), besides there are others industries dispersed over all the FD, that consume 1.5 m^3/s. The principal industrial groups are: Paper and Celulose, Chemical Products, Iron and Steel, Non metalic minerals, Textils and Foods. Table 15 presents a general vision of those industries. 165 pollutant have been measured in 15 sampling points and the ranges of variaton of the first results are shown in the table 16. Figure 10 shows a zoning of industrial in fluence. In the north exists a market for renovated waters. In the central part the influence is low and towards the south the influence is medium. Based on- the analysis of the results of the different sampling points it was concluded that the influents to the Chapultepec treatment plant have a minimum of industrial influence and are considered as tipically domestic for th FD. It is interesting to observe that the water from the Central -- Main of the deep drainage in Tepeji del Rio, Hgo. (about 40 Km of th FD) which receives the industrial wastes from the northern of the City has a similar quality to Chapultepec, because of the autopurification process, and these waters are used without treatment for irrigation purposes (table 17).

6.3 Analytical Methodology and Technology for the PCB analysis of waters

The results of this project permit to make the following conclusions:

It is convenient to count with the analitical instrument for the identification and quantification of the principal industrial contaminants -- that are not degradable in the treatment process.

In Mexico there is not production of advanced instruments (GLC, AAE, MS, UVE, IRE) and only exists production of minor laboratory equipment; the technology is mostly old and the maintenance and repair services are inadequated.

Table 18 presents the main companies and the instruments that they distribute.

As a first step for the development of national technology is possible - to produce at the universities and superior institutes monitoring equipment for pH, turbidity, temperature, conductivity, etc.

Analizing several alternatives (table 19) for the monitoring and PCB control of the waters, the costs per analysis of a sample in a central laboratory goes from $ 767.00 to 5,083 (pesos, 1980) measuring 26 and 65 parameters respectively. At the laboratories of the wastewaters treatment plants, can be measured 18 parameters at a cost of $ 452.00

This panorama compels to develop technology to make cheaper the costs of quality control.

6.4 Technology for wastewater treatment

The main objective of this study was to identify and evaluate new systems, process and dispositives for the treatment of wastewaters and the disposal and management of sludges, taking into account the national technological development and the capacity for adequate foreign technology.

13 processes were analized (table 20), corresponding to secondary and tertiary treatment systems and the management and disposal of the sludges - generated in these systems.

The results indicate the feasability of incorporate to the national technology the dispositives required for each process, but it is important - to carry the necessary research to optimize the transfer of technology.

6.5 Demonstration project of an advanced wastewater treatment pilot plant

The objective of this project is to determine the technological potential required for building a system of advanced wastewater treatment, and the quality of the effluents under distinct levels of treatment; another objective of this project is to prepare human resources and give the alternatives to develop regulations of renovated waters.

The criteria considered for its design were: physical, chemical and biological quality of the effluent similar to that of potable water; flexibility for water by passed to different units and possibility to doubled the flow rate to simulate variations on the organic contents; for the hydraulic control and physical, chemical and biological metering, sensors will be placed in situ, connected to a computer in order to -- obtain data, to process them and to control the system.

The design flow rate is 10 l/s (864 m^3/ d) and the plant has the following units: grit chamber, screens, primary settling basin, aeration tank, (alternatives: biodiscs and/or deep shaft), secondary settling basin, detergent (ABS) removal tank, mixing chamber, floculation chamber, clarifier, gas stripping tower, rapid filters, recarbonation chamber, ozonation tank, activated carbon columns, chlorination tank, and storage tank. The flow diagram is shown in figure 11.

6.6. Demonstration project of aquifer recharge with treated wastewater

Figure 12 presents part of the former experience in the Valley of Mexico and we can see that the main limitations for groundwater recharge are- the physical, chemical and biological quality of water and urban growth. Quality has decreased because of wastewater discharge into these rivers - and urban growth has reduced the area for possible recharge.

Therefore, the objective of this project is to determine the technological and economical potential needed for aquifer recharge with treated - wastewater from a biological treatment system using infiltration ponds. The project consist of the following phases:

1. Selection of the recharge sites
2. General project design
3. Operation of the system and attainment of design parameters
4. Running a full scale system

In order to follow the first phase of the project, different alternatives for ubication of the ponds at the experimental phase have been analized. Table 21 resumes the results at present defining the west zone of "Sierra de Santa Catarina" as the best place for this project. Figure 13 shows- its situation while figure 14 presents the cross section of the area.

During the tests, a flow rate of 10 000 m^3/d will be used, with an expected infiltration of 3.65 millions m^3/year. The recharge area will be of - about 2 Ha. considering the mean infiltration rate as 1.0 m/d. It has -- been estimated that water will remain in the aquifer approximately two - years.

6.7 Evaluation on health effects

The objectives in this study are the evaluation of the physical, chemical and biological quality of wastewater generated in the Federal District - to determinate if the treatment systems are efficient in removing the pollutants present in wastewater; to evaluate treatment alternatives in order to increase the physical, chemical and biological quality of the effluents from the treatment systems; to prepare the methodology to follow in order to evaluate and epidemiological aspects of the pollutants present in the water depending on their quality and potential use. The renovated information obtained from this work will be used to structure criteria do determinate the physical, chemical and biological quality of treated wastewater.

The analitic results from the samples collected in the sewage system were discussed in point 6.2. Regarding the ability of the treatment systems - for the removal of pollutants, table 22 shows the results as an index - which permits to compare the effluents of Cerro de la Estrella and Ciudad Deportiva plants, taking the effluent quality of Chapultepec plant as a guide.

Through bibliographic research data have been obtained in order to pre--

dict the behavior of each pollutant under natural conditions and under different processes in the most used treatment systems. Tables 23 and 24 resume this study which permits to determinate the limits of refractary pollutants depending on the water uses, the effects upon human health and the unwanted enviromental effects. The methods followed for the toxicological evaluation of the pollutants present in wastewater are given in figure 15.

6.8 Legislation

Of the regulating elements which conform the legal present background, regulations for pollution control states the physical, chemical and biological quality within which natural sources of water must be kept in order to assure their use, by means of the statement of basic parameters which must be considered by those who are responsible of municipal or industrial discharges. Apart from this rulement there does not exist another which states the physical, chemical and biological quality of the waters discharged into the sewage system and the quality expected from treated wastewater depending on the use it will receive.

6.8.1 Regulation for the sewage systems

There already exists a preliminary project which searchs the regulation of the relations between those in charge of the sewage system and the people which will use it. In order to establish the quality of the wastewater to be accepted in the system, the information obtained from the monitoring program will be used as to suggest the users the best technology for the sewage system itself or for the use it will receive.

6.8.2 Regulations for renovated wastewater

For this regulations there is information available about the quality of the water, reability of the systems, and a preliminary evaluation of the health effects following the use of these waters. A preliminary project will be developed before the end of this year for this area. The methodology followed to state the quality criteria and standards are given in figures 16 and 17.

7. REUSE SCHEMES

It has been based on the information recopilated in other studies and - generated by this Agency itself. Seven schemes for the reuse of treated wastewaters in the Federal District are presented below and the actions needed for their implementation.

7.1 Scheme 1: No planned use of crude wastewater.

Consists in the no use of crude wastewater generated in the Valley. It has planted only for comparison with other uses.

As it was mentioned, in the Valley of Mexico are utilized 8 m^3/s in the irrigation of 18 000 Ha., the rest is for 56 000 Ha. in the Valley of- Tula, Hgo., this application has been successful mostly because the incorporation of organic matter to a soil which lacks of it. After 70- years of practice it has showed no appreciable accumulation of heavy metals in the solid and the content of salt is not dangerous yet.The health of the country men apparently has no been changed, but exist several -- plantations of vegetables which put in danger the health of the consumer.

7.2 Scheme 2: Use of renovated waters in irrigation of landscape (green areas), filling of recreational lakes and - industrial reuse.

In this scheme the renovated waters coming from 8 wastewater treatment - plants (4.2 m^3/s) and from the upgrading of Cerro de la Estrella plant- (1 m^3/s) and from the new ones "San. Luis Gardens" (0.125 m^3) and National University (0.040 m^3/s.) The total volume of 5.325 m^3/s will be -- used in the irrigation of approximately 3 000 Ha. of green areas, the -- filling of Chapultepec, San Juan de Aragon and Xochimilco lakes, and the surplus will be destined to the industries for cooling purposes and general services.

The implementation of this alternative requires to restore civil works, servomechanisms, control panels and instrumentation of the plants and distribution networks. Besides, it is required to interconnect the treatment plants to give flexibility on the operation of the system. It is necessary to establish maintenance programs and to prepare operation's handbooks to improve the treatment control.

7.3 Scheme 3: Agricultural use

There is the possibility of interchange groundwater by renovated water with some municipalities of Mexico Sate, as Chalco, Cuautitlan and Texcoco. This water will be used for irrigation of agriculture products that will not be consumed raw,this water proceeds from Cerro de la Estrella treatment plant. We estimate an interchange volume about 4.5 m^3/s. The necessary actions are: upgrading the plant, construction of water conduction and distribution network and pumping stations.

7.4 Scheme 4: Industrial, commerce, services and public uses

These activities do not require a PCB quality similar to potable water as general services, washing of common areas, vehicle washing and others The water quality should be obtained of a tertiary treatment system and its distribution involves the use of networks parallel to the potable water network. The potential users for this services are being studied.

7.5 Scheme 5: Aquifer recharge

It will be considered two recharge paths in this scheme: infiltration by ponds and direct injection. The use of these waters should be considered at along time and not in a short time, then the philosophy of this project is to store water instead of its immediate exploitation.

7.6 Scheme 6: Domestic water use

This option is to the most ambitious. Technically is possible to obtain drinking water from wastewater, but there are not regulations to sanction all the needed parameters, because they are structured for protected sources and not for renovated waters. The health effects by the ingestion of trace organic and inorganic contaminants, present in renovated waters must be studied by means of epidemiological and toxicological - researchs.

7.7. Scheme 7: Water recycling

Consist in the recycling of the water into homes, industries, commerces and recreational services. At present we do not know the volumes that can be recycled, but in the near future will be convenient to consider this use.

TABLE 1. CALENDAR OF HYDRAULIC WORKS

PRE-HISPANIC PERIOD	NEZAHUALCOYOTL DYKE (1450)	AFTER THE FIRST MAJOR FLOOD
	CHAPULTEPEC AQUEDUCT (1466)	AFTER A DROUGHT
	ACUECUEXCIATL CANA (1500)	CAUSED FLOODING
COLONIAL PERIOD	SAN LAZARO DYKE (1555-1556)	REPLACED NEZAHUALCOYOTL DYKE
	RECONSTRUCTION OF GUADALUPE AND SAN CRISTOBAL ROADS (1604)	UP TO 2000 INDIANS WERE USED DAILY
	NOCHISTONGO EXCAVATIONS (1607-1608)	MAJOR ENGINEERINGS CONSTRUCTION
	NOCHISTONGO CUTTING (1630-1769)	SPECIAL TAXES LEVIED
	GUADALUPE AQUEDUCT (1765)	SUPPLYING THE NORTH AREA BECAUSE LIMITED CHAPULTEPEC SOURCE
MEXICAN INDEPENDENCE		1979 PESOS PER INHABITANT
	TEQUIXQUIAC TUNNEL AND GRAN CANAL DEL DESAGUE (1866-1902)	$ 2,500.00
	SAN LAZARO STATION (1883)	$ 100.00
	FIRST GENERAL DRAINAGE IN MEXICO CITY (1895-1903)	$ 1,100.00
MODERN MEXICO	XOCHIMILCO SYSTEM (1903-1913)	$ 1,600.00
	XOTEPINGO PLANT (1940)	$ 400.00
	1st STAGE LERMA DEVELOPMENT (1952)	$ 900.00
	GENERAL DRAINAGE SYSTEM (1960)	$ 700.00
	EXTENSION AND REHABILITATION OF THE GRAN CANAL (1968)	$ 250.00
	EXTENSION OF THE LERMA SYSTEM (1974)	$ 500.00
	DEEP DRAINAGE SYSTEM (1975)	$ 700.00

TABLE 2 URBAN PROBLEMS RELATED TO LAND AND WATER MANAGEMENT

● OVER - EXPLOITATION
● SINKING
● UNCONTROLLED URBAN GROWTH
● PRINCIPAL RUN - OFFS
● WATER POLLUTION
● INADEQUATE LAND MANAGEMENT
● BLOCKAGES
● MINOR INFILTRATION
● DETERIORATION OF THE ENVIRONMENT
● NON - INTEGRATED HYDROLOGICAL PLANNING IN THE METROPOLITAN AREA OF MEXICO CITY

TABLE 3 PROBLEMS WITH THE POTABLE WATER SYSTEM

● AQUIFER'S OVER - EXPLOITATION
● TECHNICAL, ECONOMICAL AND SOCIAL TROUBLES TO IMPORT WATER FROM OTHER BASINS
● LEAKS IN SOME AREAS BECAUSE SINKING OF THE SUBSOIL
● WATER QUALITY CONTROL
● POOR PREVENTIVE MAINTENANCE

TABLE 4 PROBLEMS WITH THE PRESENT DRAINAGE SYSTEM

● 2 MILLION IN HABITANTS LACKING DRAINAGE IN 1978
● INSTALLATIONS PREMATURELY OBSOLETE
● DEFICIENT SERVICE IN LOW AND SINKING AREAS
● INTERFERENCE WITH URBAN INSTALLATIONS
● DEPOSITING OF SLUDGE AND GARBAGE
● DISCHARGES IN OPEN DRAINS
● INACCURATE MEASUREMENTS
● POOR MAINTENANCE

TABLE 5 EXISTING TREATMENT PLANTS

PLANT	YEAR OPERATIONS STARTED	INSTALLED CAPACITY l/s	TREATMENT	USE (++)
CHAPULTEPEC 1st. STAGE	1956	80	A.S.	I.L.
2nd. STAGE	1958	80	A.S.	I.L.
CIUDAD DEPORTIVA 1st. STAGE	1958	80	A.S.	I.L.
2nd. STAGE	1963	150	A.S.	I.L.
XOCHIMILCO 1st. STAGE	1959	400	A.S.	I.L.
2nd. STAGE	1967	850	A.S.	I.L.
CERRO DE LA ESTRELLA 1st. STAGE	1973	2000	A.S.	I.L.
BOSQUE DE LAS LOMAS	1974	55	E.A.	I.
GUADALUPE AQUEDUCT	1978	80	A.S.	I.
SAN JUAN DE ARAGON	--	500	A.S.	I.
EL ROSARIO		25	A.S. + ADVANCED	I.

- Due to the age of some plants, a program of rehabilitation is being carried out at:
  - Catchmentand conduction network leading to the plant
  - Treatment systems
  - Distribution networks

(+) A.S. Activated Sludge E. A. Extended Aeration

(++) I. Irrigation green areas L. Recreational lakes

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CERRO DE LA ESTRELLA Ist. STAGE	1973	2000	A.S.	I.L.
BOSQUE DE LAS LOMAS	1974	55	E.A.	I.
GUADALUPE AQUEDUCT	1978	80	A.S.	I.
SAN JUAN DE ARAGON	--	500	A.S.	I.
EL ROSARIO		25	A.S. + ADVANCED	I.

- Due to the age of some plants, a program of rehabilitation is being carried out at:
  - Catchmentand conduction network leading to the plant
  - Treatment systems
  - Distribution networks

(+) A.S. Activated Sludge   E. A. Extended Aeration

(++) I. Irrigation green areas   L. Recreational lakes

TABLE 6 SUPPLY AND DEMAND IN RELATION TO THE AMOUNT OF RENOVATED WATER

TREATMENT PLANT IN OPERATION	Year STARTED	Capacity in l/s			Water Balance, in l/S				Irrigation of green aereas, ha		Lakes, in l/s		Cost in pesos m^3 (3)
		Installed	USED	η (1)	Supply	Demand	Excess	Defici (2)	Supply	Demand	Supply	Demand	
Chapultepec	1956	160	100	62	100	42	58		600	410	+	39	3.65
S.J. Aragón	1964	500	180	36	180	104	76		675	350	+		2.16
Cd. Deportiva	1958	230	200	87	200	75	125		345	245	+		2.12
C. de la Estrella	1971	2000	1000	50	1000	1000	0	1000			+	1000	0.33
Bosque de las L.	1973	55	12	22	12	0	12		50				5.64
Gpe. Acueduct		60	80	0	0	0	0						1.21
Xochimilco	1959	1250	240	32	400	0	400				+	400	0.93
T O T A L		4275	1812	44	1892	1221	701	1000	1750	1005		1439	0.68

1. Efficiency capacity utilized compared to installed capacity.

2. Deficit of water balance in feb. march and april

3. Cost of renovated water in pesos/m^3 without taking into account investment or depreciation of equipment or infraestructure required.

TABLE 7 SUPPLY AND DEMAND ACCORDING TO THE QUALITY OF RENOVATED WATER

TREATMENT PLANTS	TREATMENT PROCESS					HYDRAULIC CONTROL					PCB CONTROL OF THE PROCESS AND EFFLUENT QUALITY														
	Supply	DEMAND USE									BOD	COD	DO	TSS VSS	SS	N	P	G O	TDS	PH	T	MBAS	CL_2	MPN	Control PCB %
		AI	IGA	FL	I	Q	Qr	Qw	Qa	Qe															
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)													(11)	(12)	(13)
Chapultepec	AS	+	+	+	°						°	°	°	°	°					°	°		°		53
Sn. Juan de Aragón	AS	+	+	+	°						°		°		°					°	°		°		37
Cd. Deportiva	AS	+	+	+	°						°	°	°	°	°	°				°	°		°		58
Cerro de la Estrella	AS	+	+	+	°						°	°	°		°					°	°		°		47
Bosque de las Lomas	EA	+	+	+	°																				32
Guadalupe Aqueduct	AS	+	+	+																					
Xochimilco	AS	+	+	+	°						°	°			°										21

(1) Treatment process in the Plant
A.S.- Activated Sludge
E.A.- Extended Aeration
(2) Agricultural irrigation
(3) Irrigation of Green Areas
(4) Filling of lakes
(5) Industrial uses.
The treatment process is apparently adequate
(6) Q Rate of inflow to the plant
(7) Qr Rate of recirculation of sludge
(8) Qw Rate of removal of excess sludge
(9) Qa Air flow in the aeration units
(10) Qe Flow of treated effluent

(11) Residual chlorine
(12) MPN/100 ml. Most Probable Number of organisms per 100 ml of Sample
(13) Efficiency in the PCB control of the process and renovated water, as a percentage.

+ Use of renovated water

° Analized parameter

TABLE 8 PROBLEMS ON THE TREATMENT AND REUSE PROGRAM

- PARTIAL UTILIZATION OF THE INSTALLED CAPACITY
- POOR MAINTENANCE
- INCOMPLETE INFRAESTRUCTURE FOR CATCHMENT, CONDUCTION AND DISTRIBUTION
- LIMITED USES (IRRIGATION OF GREEN AREAS AND RECREATIVE LAKES)
- LIMITED INFORMATION RELATED WITH THE POTENTIAL MARKET OF RENOVATED WATERS
- ADVERSE EFFECTS OF INDUSTRIAL WASTES IN TREATMENT PROCESSES
- INCIPIENT TECHNOLOGICAL DEVELOPMENT
- LIMITED TRAINING OF OPERATORS AND MAINTENANCE PERSONNEL
- LACK OF LEGISLATION
- LIMITED INFORMATION RELATED TO HEALTH AND ENVIRONMENT EFFECTS CAUSED BY THE REUSE OF WATER
- LIMITED ECONOMIC RESOURCES

TABLE 9 WATER SUPPLY FORECAST

• BY THE YEAR 2000: 71 m^3/s WILL BE NEEDED
• SEARCH OF ALTERNATIVES FOR SUPPLY, OTHERWISE INCREASE IN THE OVER-EXPLOITATION OF THE AQUIFERS, WITH DETERIORATION OF WATER QUALITY AND WORSE SINKING
• REDUCTION IN THE AMOUNT OF WATER IMPORTED FROM THE LERMA VALLEY
• NEED TO SUPPLY THE POPULATION WHO IS SETTLEMENT ABOVE THE LEVEL OF ACTUAL SUPPLIES
• INCREASE IN COMPETITION BETWEEN VARIOUS USERS
• NECESSITY TO IMPORT WATER FROM OTHER BASINS

TABLE 10 DRAINAGE FORECAST

• MORE AND FASTER RUN-OFFS
• CHANGES ON OPERATION EFFICIENCY
• THE SOUTH-EAST AREA OF THE CITY CANNOT BE DRAINED BY PRESENT SYSTEMS
• 50 m^3/s WASTEWATER PRODUCED BY THE YEAR 2 000
• POTENTIAL POLLUTION OF THE AQUIFER BY WASTEWATER DISCHARGES
• DETERIORATION OF SURFACE WATER QUALITY
• TO COMPLETE THE SYSTEMS, OTHERWISE INCREASE IN POOLING AND FLOODING

TABLE 11 TREATMENT AND REUSE SYSTEMS FORECAST

• $4.2\ m^3/s$ OF CONTROLLED TREATED WATERS
• RECUPERATION OF DRINKING WATER TO BE PROVIDED TO POPULATION
• CONTROL OF ADVERSE EFFECTS TO THE HUMAN HEALTH AND ENVIRONMENT
• REDUCED VOLUMES OF POTABLE WATER IMPORTED INTO THE VALLEY OF MEXICO
• REDUCED OVER-EXPLOITATION OF THE VALLEY'S AQUIFER
• IMPROVED PLANNING FOR THE MANAGEMENT AND CONTROL OF THE WATERS INTO THE VALLEY
• CAPACITY OF TECHNOLOGY DELOPMENT ADECUATED TO OUR OWN ENVIRONMENT
• QUALIFIED HUMAN RESOURCES FOR SYSTEMS MANAGEMENT

TABLE 12 HYDRAULIC PRINCIPLES

• EFFICIENT USE OF WATER, AVOIDING WASTE AND LEAKS
• TO REUSE TREATED WASTEWATER
• TO INTENSIFY THE CONSERVATION OF WATER IN THE VALLEY OF MEXICO
• TO IMPORT SUFFICIENT WATER TO COVER DEFICIENCIES LEFT BY THE FOREGOING ACTIVITIES

TABLE 13 DESCRIPTION OF BASIC STUDIES

TITLE	OBJECTIVES	APPLICATION OF RESULTS
* Uses of water	- Determine the water uses by the Federal District inhabitants.	- Determine the potential market for renovated water. Location of users in order to site the - treatment plants accordingly
* Physical-chemical Biological Quality required in renovated water	- Determine the PCB quality requirements for renovated water according to its use.	- Determine the technological requirements for water treatment and monitoring. Information to help prepare the regulation sanctioning renovated water quality.
* Characteristics of wastewater	- Determine the PCB characteristics - of wastewater generated in the Federal District in order to establish treatment levels	- Information for the Regulation which will cover the uses the drainage system. - Determine the required treatment technology according to use - Information to structure and operate the water monitoring network - Information for the design of the pilot - plant.
* Technical developments: Advanced -- treatments systems	- Determine the state of the art for advanced treatment of wastewater technology.	- Information to selett equipment for the pilot plant. Recognize the level of efficiency activied in the removal of pollutants with new treatment process.
* Technical developments: Analytical-Monitoring of PCB	- Identify the technology required for automatic control of treatment systems	- Determine the advances in the field of automatic control. In the short term, automate the existing treatment system. In the medium and long term develope a means of - control by computer to program the treatment systems which would allow the aquisction, - feed back and processing of the information regarding the functioning of theses systems - Determine the reliability required for treatment systems - Information the regulation covering the quality of renovated water.

TABLE 13 DESCRIPTION OF BASIC STUDIES (cont)

TITLE	OBJECTIVES	APPLICATIONS FOR RESULTS
Project: Pilot Plant for advanced treatment of wastewater	- Design, build and operate a pilot plant in order to evaluate processes and treatment alternatives. To obtain cost indexes and design parameters for large scale systems. - Determine requirements in the fields of technological development and human resources.	- Determine the technological requirements and the possibilities of adapting them to national conditions. - Information to implement a technological development plan which allows the aims of the program to be met. - Determine the PCB quality which national technology would allow to be reached and establish which uses the treated water could be put do. Information for the regulation sanctioning PCB quality for renovated water. - Information and resources to carry out studies evaluating the damage to health and the environment.
Project: Recharging aquifers with renovated water.	- Determine the technological requirements for recharging and subsequent exploitation of aquifers.	- Evaluate the technological requirements which a project of this nature needs. Determine the potential of this practice in future years. Information for the regulations which sanction the water quality necessary for recharging and the quality of renovated water for subsequent use.
* Evaluation of damage to health	- Evaluate the potential effects of damage to health related to direct or indirect reuse of renovated water.	- Identify treatment levels and technological requirements for the analytical monitoring of renovated water. Information to establish quality criteria. Information for the regulation sanctioning the PCB quality of renovated water. Structure prevention and protection measures for the users.
* Evaluation of Environmental Impacts	- Identify and evaluate the impacts on the environment caused by the use of renovated water.	- Information for the selection of alternatives which produce the least alteration in the environment by the use of renovated water. Information for the regulation sanctioning the PCB quality of renovated water.

TABLE 13 DESCRIPTION OF BASIC STUDIES (cont)

TITLE	OBJECTIVES	APPLICATIONS OF RESULTS
* Public acceptance	- Orientate public opinion related to the reuse of water.	- Information to structure the publicity compaigns related to reuse. - Establishment of proper channels of communication to inform the public about reuse.
* Regulation sanctioning the PCB quality of renovated water and its uses.	- Establish the PCB quality which renovated water should have, according to its use, as well as the operation of the systems producing them.	- Establish the policies which alienate the reuse of renovated water - To have a legal instrument regulating the activities related to the use of renovated water. - Protection of human health and the environment-- related to the production, use and disposal of - renovated water.
* Development of Human Resources	- Prepare the necessary personnel in all areas related to reuse, in order to have reliable operators, administratos and developments - within the system.	- Information to outline the requirements and training programs. - Information to structure training plans which satisfy the needs of the program. This should be carried out in conjuction with the institutes of higher education.

TABLE 14 WATER CONSUMPTIONS BY SECTORS IN THE FEDERAL DISTRICT (m^3/s)

YEAR USE	1975	1980	1990	2000
DOMESTIC	25.9	23.5	32.5	45.3
INDUSTRIES	4.5	6.0	8.8	5.8
COMMERCE AND SERVICES	4.5	7.2	10.4	13.2
PUBLIC AND RECREATIONAL	4.0	5.3	5.8	6.7
AGRICULTURE	0.1	0.2	0.2	0.0
TOTAL	39.0	42.2	57.7	71.0

TABLE 15 INDUSTRIES LOCALIZED IN THE FEDERAL DISTRICT

INDUSTRIES SECTOR	NUMBER	PRODUCTION Million pesos for year (1978)
1. Packing fruits and legumes	50	937
2. Products of mill	1 282	3 125
3. Livestock kill	175	937
4. Milk products	100	1 781
5. Candies	115	3 562
6. Alcoholic drinks	32	812
7. Beer	7	3 375
8. Refreshment	28	2 688
9. Textile mills	871	7 438
10. Leather tanning and finishing	292	812
11. Pulp and paperboard mills	564	438
12. Paper products	255	3 563
13. Printing and publishing	2 604	7 312
14. Chemical manufacturing	30	563
15. Fertilizers and pesticides	10	125
16. Resins and sinthetic fiber	10	750
17. Paints and ink	42	1 000
18. Pharmaceuticals	295	9 000
19. Soap and detergent manufacturing	175	8 125
20. Animal and vegetal oils	12	137
21. Petroleum refining	18	563
22. Coal mining	760	6 906
23. Rubber processing	47	218
24. Procelain enamel	122	1 218
25. Paving and roofing materials	22	312
26. Iron and steel manufacturing	70	2 500
27. Non ferrous metals manufacturing	45	4 125
28 Metalic finished	3 423	11 000
29. Electrical and electronic components	633	8 125
30. Automotive industry	267	11 000

TABLE 16 CONCENTRATIONS OF POLLUTANTS IN RAW WASTEWATER AND SEDIMENTS

(Units in mg/l, except pH and otherwise stated)

WATER	Low	High
1.- TOTAL ALKALINITY (CaCO3)	166.0	575.5
2.- PHENOLPHTHALEIN ALKALINITY (CaCO3)	0.0	0.0
3.- CARBONATE (CaCC3)	0.0	0.0
4.- BICARBONATE (CaCo3)	166.0	575.5
5.- HYDROXILE (CaCO3)	0.0	0.0
6.- ELECTRICAL CONDUCTIVITY (µMHOS/cm)	800.0	4,109.00
7.- TS	470.0	6,174.00
8.- TFS	197.0	1,037.0
9.- TVS	273.0	5,136.0
10.- TDS	392.0	2,510.0
11.- FDS	186.0	335.0
12.- VDS	206.0	2,686.0
13.- TSS	78.0	2,755.0
14.- FSS	11.0	702.0
15.- VSS	67.0	2,938.0
16.- SETTEABLE SOLIDS (ml/l)	3.87	77.0
17.- pH	6.0	7.5
18.- DBO 5 (SOLUBLE)	110.0	746.0
19.- COD (SOLUBLE)	120.0	1,356.0
20.- TOC	31.0	417.0
21.- GREASE AND OIL	72.0	4,131.0
22.- M.B.A.S.	2.6	6.9
23.- N-NH3	14.2	44.9
24.- TOTAL NITROGEN	34.0	83.0
25.- N-NO3	1.5	78.0
26.- CHLORIDE	25.5	536.5
27.- BORON	1.89	25.6
28.- TOTAL PHOSPHORUS	5.4	90.6
29.- S.A.R.(SOLUBLE)	3.159	11.228
30.- S.A.R. TOTAL	3.444	14.350
31.- FECAL COLIFORMS (10^6ORGS/100 ml)	17.70	197.25
32.- TOTAL COLIFORMS (10^6ORGS/100 ml)	25.98	343.75
METALS		
33.- CALCIUM (SOLUBLE)	6.0	23.2
34.- CALCIUM (TOTAL)	16.2	96.9
35.- MAGNESIUM (SOLUBLE)	9.5	45.5
36.- MAGNESIUM (TOTAL)	54.1	149.6
37.- SODIUM (SOLUBLE)	52.8	435.2
38.- SODIUM (TOTAL)	86.1	510.7
39.- POTASSIUM (SOLUBLE)	4.2	68.9
40.- POTASSIUM (TOTAL	12.7	113.4

TABLE 16 CONCENTRATIONS OF POLLUTANTS IN RAW WASTEWATER AND SEDIMENTS (cont)

	Low	High
41.- IRON (SOLUBLE)	0.9	50.5
42.- IRON (TOTAL)	7.9	72.2
43.- MANGANESE (SOLUBLE)	0.012	0.146
44.- MANGANESE (SOLUBLE	0.060	0.860
45.- LEAD (SOLUBLE)	0.018	0.190
46.- LEAD (TOTAL)	0.176	0.450
47.- CADMIUM (SOLUBLE)	0.001	0.020
48.- CADMIUM (TOTAL)	0.001	0.040
49.- MERCURY (SOLUBLE)	0.0009	0.014
50.- MERCURY (TOTAL)	0.002	0.019
51.- ARSENIC (SOLUBLE)	0.017	0.036
52.- ARSENIC (TOTAL)	0.019	0.170
53.- CHROMIUM (SOLUBLE)	0.010	0.365
54.- CHROMIUM(TOTAL)	0.053	0.793
PURGEABLE ORGANICS		
55.- 1,1 DICHLOROETHANE	0.0	0.156
56.- 1,1 DICHLOROETHYLENE	0.0	0.140
57.- 1,1,2 TRICHLOROETHANE	0.0	0.177
58.- 1,1,2,2, TETRACHLOROETHANE	0.0	0.180
59.- CHLOROETHANE	0.0	0.006
60.- 2-CHLOROETHYL VINIL ETHER	0.0	0.048
61.- CHLOROFORM	0.001	0.196
62.- 1,2-DICHLOROPROPANE	0.0	0.006
63.- 1,3-DICHLOROPROPANE	0.0	0.002
64.- METHYLENE CHLORIDE	0.0	0.187
65.- METHYL BROMIDE	0.0	0.007
66.- BROMOFORM	0.0	0.007
67.- DICHLOROBROMOMETHANE	0.0	0.008
68.- TRICHLOROFLUOROMETHANE	0.0	0.003
69.- DICHLORODIFLUOROMETHANE	0.0	0.005
70.- CHLORODIBROMOMETHANE	0.0	0.014
71.- TETRACHLOROETHYLENE	0.0	0.340
72.- TRICHLOROETHYLENE	0.0	0.770
73.- VINYL CHLORIDE	0.0	0.308
74.- 1,2-TRANS-DICHLOROETHYLENE	0.0	0.0
75.- bis-(CHLOROMETHYL)ETHER	0.0	0.0
76.- BENZENE	0.0	1.403
77.- TOLUENE	0.009	1.275
78.- ETHYLBENZENE	0.009	0.329
79.- CARBON TETRACHLORIDE	0.0	0.520
80.- CHLOROBENZENE	0.0	0.143
81.- 1,2-DICHLOROETHANE	0.0	0.520
82.- 1,1,1,-TRICHLOROETHANE	0.0	0.862
BASE/NEUTRAL EXTRACTABLE ORGANIC		
83.- 1,2-DICHLOROBENZENE + 112	0.0	0.359
84.- 1,2-DICHLOROBENZENE	0.0	3.715
85.- 1.4-DICHLOROBENZENE	0.0	1.247
86.- HEXACHLOROETHANE	0.0	0.389
87.- HEXACHLOROBUTADIENE	0.0	0.0
88.- HEXACHLOROBENZENE	0.0	0.100

TABLE 16 CONCENTRATIONS OF POLLUTANTS IN RAW WASTEWATER AND SEDIMENTS (cont)

	Low	High
89.- 1,2,4-TRICHLOROBENZENE	0.0	0.593
90.- bis(2-CHLOROETHOXY) METHANE	0.0	0.0
91.- NAPHTHALENE	0.0	0.092
92.- 2-CHLORONAPHTHALENE	0.0	0.050
93.- ISOPHORONE	0.0	0.056
94.- NITROBENZENE + 126	0.0	1.304
95.- 2,4-DINITROTOLUENE	0.0	0.107
96.- 2,6-DINITROTOLUENE	0.0	0.187
97.- FLUORENE + 95	0.0	0.187
98.- FLUORANTHENE	0.0	0.250
99.- CHRYSENE	0.0	0.147
100.- PYRENE	0.0	0.022
102.- PHENANTHRENE	0.0	0.134
103.- ANTHRANCENE + 119	0.0	0.086
104.- BENZO (a) ANTHRACENE	0.0	0.096
105.- BENZO (k) FLUORANTHENE	0.0	0.010
106.- BENZO (b) FLOURANTHENE	0.0	0.010
107.- BENZO (a) PYRENE	0.0	0.012
108.- INDENO (1,2,3, c,d) PYRENE	0.0	0.376
109.- DIBENZO (a,h) ANTHRACENE	0.0	0.005
110.- BENZO (g,h,i)PERYLENE	0.0	0.040
111.- 4-CHLOROPHENYL PHENYL ETHER	0.0	0.0
112.- 3,3-DICHLOROBENZIDINE + 118	0.0	0.024
113.- BENZIDINE	0.0	0.033
114.- bis (2-CHLOROETHYL) ETHER	0.0	0.359
115.- 1,2-DIPHENYLHYDRAZINE	0.0	0.0
116.- HEXACHLOROCYCLOPENTADIENE	0.0	0.280
117.- N-NITROSODIPHENYLAMINE	0.0	0.440
118.- 4-BROMOPHENYL PHENYL ETHER	0.0	0.0
119.- bis-(2-ETHYLHEXYL) PHTHALATE	0.0	0.084
120.- DI-n-OCTYL PHTHALATE	0.0	0.234
121.- DIMETHYL PHTHALATE	0.0	0.086
122.- DIETHYL PHTHALATE	0.0	3.700
123.- DI-n-BUTYL PHTHALATE	0.0	0.069
124.- ACENAPHTHYLENE	0.0	0.390
125.- ACENAPHTHENE	0.0	0.230
126.- BUTYL BENZYL PHTHALATE	0.0	0.316
127.- N-NITROSODIMETHYLAMINE	0.0	0.005
128.- N-NITROSODI-n-PROPYLAMINE	0.0	1.300
129.- bis (2-CHLOROISOPROPYL) ETHER	0.0	0.390
ACID EXTRACTABLE ORGANICS		
130.- PHENOL	0.0	0.472
131.- 2-NITROPHENOL	0.0	5.980
132.- 4-NITROPHENOL	0.0	23.860
133.- 2,4-DINITROPHENOL	0.0	1.820
134.- 2,6-DINITRO-o-CRESOL		26.780
135.- PENTACHLOROPHENOL	0.017	5.325
136.- p-CHLORO-m-CRESOL	0.0	46.640
137.- 2-CHLOROPHENOL	0.0	0.458
138.- 2,4-DICHLOROPHENOL	0.024	3.200

TABLE 16 CONCENTRATIONS OF POLLUTANTS IN RAW WASTEWATER AND SEDIMENTS (cont)

	Low	High
139.- 2,4,6-TRICHLOROPHENOL	0.0	4.342
140.- 2,4-DIMETHYLPHENOL	0.0	1.258
PESTICIDES/PCB'S		
141.- (a y b) ENDOSULFAN	0.0	0.0
142.- (a,b,g,d) BHC	0.0	0.217
143.- ALDRIN	0.0	0.060
144.- DIELDRIN	0.0	0.030
145.- 4,4'DDE	0.0	0.003
146.- 4,4'DDD	0.0	0.005
147.- 4,4'DDT	0.0	0.200
148.- HEPTACHLOR	0.0	0.010
149.- HEPTACHLOR EPOXIDE	0.0	0.0
150.- CHLORDANE	0.0	0.127
151.- TOXAPHENE	0.0	0.065
152.- AROCLOR 1016	0.0	0.0
153.- AROCLOR 1221	0.0	0.0
154.- AROCLOR 1232	0.0	0.0
155.- AROCLOR 1242	0.0	0.0
156.- AROCLOR 1248	0.0	0.0
157.- AROCLOR 1254	0.0	0.0
158.- AROCLOR 1260	0.0	0.0
SLUDGE AND SEDIMENTS		
1.- MOISTURE (%)	10.26	99.68
2.- TS (WET BASIS,%),	0.32	23.73
3.- ASHES (WET BASIS, %)	0.064	12.57
4.- ORGANIC MATTER (WET BASIS,%)	0.27	11.15
5.- ASHES (DRY BASIS, g/kg)	21.36	530.6
6.- ORGANIC MATTER (DRY BASIS, g/kg)	546.00	872.2
7.- TOTAL PHOSPHORUS (DRY BASIS, g/kg)	1.44	28.68
8.- TOTAL NITROGEN (DRY BASIS, g/kg)	17.29	156.00
9.- N-NH3 (DRY BASIS, g/kg)	4.10	59.41
10.- BORON (DRY BASIS, g/kg)	0.19	0.591
11.- S.A.R.	0.031	2.164
METALS (DRY BASIS, g/kg)		
12.- Na	0.342	28.14
13.- K	0.336	13.30
14.- Ca	0.046	23.00
15.- Mg	0.009	10.45
16.- As	0.000	0.04
17.- Pb	0.027	1.132
18.- Hg	0.083	2.48
19.- Cr	0.013	0.682
20.- Cu	0.031	0.831
21.- Mn	0.006	0.479
22.- Fe	0.203	29.02
23.- Zn	0.028	4.23
24.- Cd	0.002	0.170

TABLE 17 COMPARATIVE INDEX OF PHYSICAL, CHEMICAL AND BIOLOGICAL QUALITY OF THE FEDERAL DISTRICT WASTEWATER

Station \ Parameter	Minerals	Solids	Nutrients	Grease and Oils	Organic matter	Organic carbon	Purgeable organics	Acid extractable organics	Base/Neutral extractable orgs	Pesticides	Heavy metals	Alcalineterre	Biologics	Sum	Relation discharge/disch # 8	Contamination level
1	0.7	1.8	0.3	0.7	3.0	4.1	10.4	0.1	1.5	0.005	1.3	1.7	13.2	38.8	3.17	6
2	0.8	2.4	0.4	0.6	3.4	6.5	4.1	0.1	0.7	0.01	1.3	1.8	13.5	35.5	2.9	5
3	0.01	1.4	0.4	0.5	3.8	4.1	38.2	0.5	3.3	0.1	1.7	2.4	10.9	65.3	5.44	8
4	0.8	3.5	0.5	7.1	2.7	3.6	32.8	1.2	1.0	0.03	1.9	2.3	8.8	66.2	5.52	9
5	0.6	1.4	0.3	1.0	1.9	2.6	35.8	0.5	1.4	0.4	1.4	1.7	9.4	58.4	4.87	7
6	0.4	1.7	0.4	1.7	2.5	3.1	ND	0.4	0.3	ND	2.2	1.4	1.7	15.8	1.32	2
7	1.1	3.1	0.4	0.8	1.6	1.5	153.8	0.9	6.8	0.04	1.5	2.1	15.1	188.7	15.7	15
8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	ND	1.0	1.0	1.0	12.0	1.0	1
9	1.0	2.7	0.7	32.5	5.6	6.7	34.3	2.7	1.9	0.05	3.3	2.0	9.6	103.5	8.63	11
10	0.6	1.5	0.4	0.9	2.2	2.1	59.2	0.5	0.4	0.006	2.2	1.7	8.0	79.7	6.64	10
11	1.0	2.1	0.5	0.9	4.1	5.5	7.2	0.1	3.3	0.1	1.4	2.7	5.5	34.4	2.87	4
12	2.0	12.9	1.1	8.7	9.1	13.5	14.5	22.3	21.2	0.1	3.2	5.7	14.6	128.9	10.7	12
13	1.3	3.6	0.5	1.7	4.8	6.0	80.2	3.6	14.0	0.5	1.5	3.1	21.7	142.5	11.8	13
14	1.2	1.7	0.4	1.8	3.3	5.2	77.6	7.6	0.3	32.7	3.4	1.7	15.2	152.1	12.6	14
15	0.5	1.3	0.2	1.9	1.1	1.7	11.7	0.1	2.8	0.03	1.6	1.6	2.1	26.9	2.2	3

1. Gran Canal (San Lázaro)
2. Gran Canal (Aragón)
3. Gran Canal (Cerro Gordo)
4. Xochiaca
5. Canal de Miramontes
6. Interceptor Poniente
7. Lumbrera No. 11
8. Chapultepec (comparative facility)
9. Colector No. 13
10. Cerro Estrella
11. Cd. Deportiva
12. Río San Javier
13. Río Tlalnepantla
14. Río de los Remedios
15. Tepeji del Río

TABLE 18 INSTRUMENTS AND EQUIPMENT

INSTRUMENTS AND EQUIPMENT	NATIONAL PRODUCTS	SUBSIDIARIES	GENERAL DISTRIBUTERS	TRADE MARK (N and F)
INSTRUMENTS				
GAS CHROMATOGRAPHS	0	5	11	5
SPECTROPHOTOMETERS UV	0	11	17	11
SPECTROPHOTOMETERS AA	0	10	17	10
SPECTROPHOTOMETERS VIS	0	11	17	11
AUTOANALYZERS	0	2	4	2
ANALYZERS OF COT	0	5	5	5
POTENTIOMETERS	1	11	18	16
CONDUCTIMETERS	0	10	12	10
ANALYTICAL BALANCES	0	5	15	5
EQUIPMENT				
GRINDS	2	-	12	5
FURNACES AND INCUBATORS	4	-	15	8
MOUFFLE FURNACE	1	-	7	5
MICROSCOPES	1	-	12	8
CENTRIFUGES	1	-	15	3
AUTOCLAVES	2	-	10	4
FUME HOOD	1	-	1	1
OTHER MATERIALS	5	-	15	8

N NATIONAL F FOREING

TABLE 19 WATER ANALYSIS COSTS

	CENTRAL LABORATORY		WWTP LAB	FIELD TESTS
	ALTERNATIVE 1	ALTERNATIVE 2		
NUMBER OF PARAMETERS PCB				
GENERAL AND SPECIFIC	26 -	26 39	18 -	7 -
EQUIPMENT (MILLION PESOS)				
GAS CHROMATOGRAPHY	-	0.80	-	-
SPECTROPHOTOMETER UV	-	0.30	-	-
SPECTROPHOTOMETER AA	1.00	1.0	-	-
ANALYZER OF TOC	0.50	0.50	-	-
ANLYTICAL BALANCES	0.10	0.25	0.05	-
OTHER EQUIPMENTS	0.85	1.00	0.35	0.50
GLASS MATERIAL	0.20	0.35	0.15	0.10
AUTOANALYZER	1.25	1.25	-	-
TOTAL	3.90	5.45	0.55	0.60
HUMAN RESOURCES (THOUSAND PESOS)				
ANNALIST AA		20.0		-
ANNALIST AB	50.0	50.0	20.0	20.0
TECHNICIANS	50.0	50.0	30.0	-
TOTAL	100.0	120.0	50.0	20.0
MONTHLY COSTS (THOUSAND PESOS)				
AMORTIZATION **	65.0	90.0	6.0	8.0
OPERATING COSTS	100.0	150.0	45.0	10.0
ADMINISTRATION COSTS	100.0	100.0	30.0	5.0
OTHERS	25.0	25.0	10.0	
SOLDS	170.0	250.0	90.0	
TOTAL	460.0	615.0	181.0	23.0
NUMBER OF PROCESSED SAMPLES DAILY (10 H)	30	7	20	20
SAMPLE COST (PESOS)	767.00	5083.00	452.40	57.50
COST PER M^3 OF TREATED WATER **	0.041	0.055	0.04 0.30	variable

WWTP Wastewater treatment plant

* (20% yearly) ** for a production of 11×10^6 m^3/month

TABLE 20 TECHNOLOGICAL ANALYSIS FOR THE WASTEWATER TREATMENT

PROCESS	REMARKS
1. Oxidation pond	Technology that can be produced in Mexico
2. Trickling filters	Technology produced in Mexico of low scale
3. Biodiscs	Complex technology to produce the sintetic media, but economic if it is applied in -- other uses.
4. Biological nutrients removal	The application ot this technology does not require changes in the existent technology
5. Aeration equipment	Technology that can be produced in Mexico
6. Lagoons with aquatic plants	This process has economical advantages in its operation.
7. Desinfection with ClO_2	The national technology is able to produce the accesories for the aplication of- ClO_2, but not for produce it.
8. Digestion with aditional carbon source	Process technology include transport equipment and sludge operation, which can be -- produced in this country but requires special research.
9. Press filter	Technology highly efficient for sludge conditioning
10. Reverse osmosis	Important national research related with saline water purification
11. Final sludge disposal	It is necessary to know the effects. benefits and damage from the application to eroded lands of Federal District.
12. Aeration	A constant development of technology which can be adapted
13. Heavy metals removal	Different kinds of technolcgy applicable to our country.

TABLE 21 CRITERIA TO SELECT RECHARGE SITE

CRITERIA \ SITE	AJUSCO	SAN MATEO XALAPA	SANTA FE	SAN JUAN DE ARAGON	STA.CATARINA P.	STA. CATARINA O.	SAN PEDRO ATOCPAN	MILPA ALTA
1. Geological structure	*	*	*		*	*	*	*
2. Hidrological characterics			*	x	*	*	*	*
3. Topographic level	x				*	*	*	*
4. Topographic configuration			x		*	x	*	*
5. Railroad					*	*	*	*
6. Land availability					*	*	x	
7. Groundwater pollution risks		x	x				x	x
8. Reuse of pumped waters					*	*	*	*
9. Availability of renovated water for overload	x				*	*	*	*
10. Overload through soils					*	*	*	*

* Adequate

x Inadequate

TABLE 22 COMPARATIVE WATER QUALITY INDEX OF WASTEWATER TREATMENT PLANTS

Wastewater treatment* plant / Parameter	Chapultepec **		Cerro de la Estrella		Cd. Deportiva	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
MINERALS	1.0	1.0	0.6	0.4	1.0	0.7
SOLIDS	1.0	1.0	1.5	1.7	2.1	3.0
NUTRIENTS	1.0	1.0	0.4	1.39	0.5	1.4
GREASE AND OILS	1.0	1.0	0.9	0.6	0.9	0.6
ORGANIC MATTER	1.0	1.0	2.2	2.1	4.1	2.1
TOTAL ORGANIC CARBON	1.0	1.0	2.1	2.3	5.5	2.1
PURGEABLE ORGANICS	1.0	1.0	59.2	4.3	7.2	2.4
ACID EXTRACTABLE ORGANICS	1.0	1.0	0.5	4.1	0.1	14.4
BASE/NEUTRAL EXTRACT.ORG.	1.0	1.0	0.4	1.0	3.3	8.6
PESTICIDES/PCB's	N.D.	N.D	0.006	0.002	0.1	0.18
HEAVY METALS	1.0	1.0	2.2	0.3	1.4	0.6
ALCALINETERRE METALS	1.0	1.0	1.7	0.9	2.7	1.8
BIOLOGICAL POLLUTANTS	1.0	1.0	8.0	0.05	5.5	0.7
Sum Inf.	12		79.7		34.4	
Relation (Influents)	1		6.64		2.87	
Sum Efl.		12		19.14		38.58
Relation (Effluents)		1		1.60		3.21

* Activated sludge ** COMPARATIVE FACILITY

TABLE 23 POLLUTANTS IN THE ENVIRONMENTAL PROCESS

PARAMETER / ENVIROMENTAL PROCESS	VOLATILIZATION	SORPTION	TRANSPORT	FOTOLISIS	OXIDATION	HYDROLISIS	BIOACUMULATION	BIODEGRADATION	CHEMICAL SPECIFICATION
MINERALS		*	*						
SOLIDS		*	*					*	
NUTRIENTS	*	*	*		*	*		*	
GREASE AND OIL		*	*	*	*			*	
ORGANIC MATTER	*	*	*	*	*	*	*	*	
PURGEABLE ORGANICS	*	*					*	*	
ACID EXTRACTEABLE ORGANICS		*	*	*			*	*	
BASE/NEUTRAL EXTRACTEABLE ORGANICS		*	*	*	*	*	*	*	
PESTICIDES	*	*	*	*			*		
HEAVY METALS		*	*				*		*
ALCALINETERRE METALS		*	*						*

TABLE 24 REMOTION OF POLLUTANTS BY DIFFERENT UNIT OPERATIONS

PARAMETER UNIT OPERATION	MINERALS	SOLIDS	NUTRIENTS	GREASE AND OIL	ORGANIC MATTER	PURGEABLE ORGANICS	ACID EXTRACTEABLE ORGANICS	BASE/NEUTRAL EXTRACTEABLE ORGANICS	PESTICIDES	HEAVY METALS	ALCALINETERRE METALS
MIXING				☆	☆						
SEDIMENTATION	☆	☆		☆	☆			☆	☆	☆	☆
COAGULATION	☆	☆			☆				☆	☆	☆
FILTRATION	☆	☆			☆			☆	☆	☆	☆
CHEMICAL OXIDATION	☆	☆	☆	☆	☆	☆	☆	☆			
CHEMICAL PRECIPITATION										☆	☆
AIR STRIPPING					☆	☆			☆		
ADSORPTION	☆	☆	☆	☆	☆		☆	☆	☆	☆	☆
DISINFECTION						☆					
AEROBIC TREATMENT	☆	☆	☆	☆	☆		☆	☆	☆	☆	☆
ANAEROBIC TREATMENT	☆	☆	☆	☆	☆			☆		☆	☆
FACULTATIVE TREATMENT	☆	☆	☆	☆	☆		☆	☆	☆	☆	☆
IONIC EXCHANGE	☆	☆	☆							☆	☆
REVERSE OSIMOSIS	☆	☆	☆		☆		☆	☆	☆	☆	☆
ELECTRODIALYSIS	☆	☆	☆		☆					☆	☆

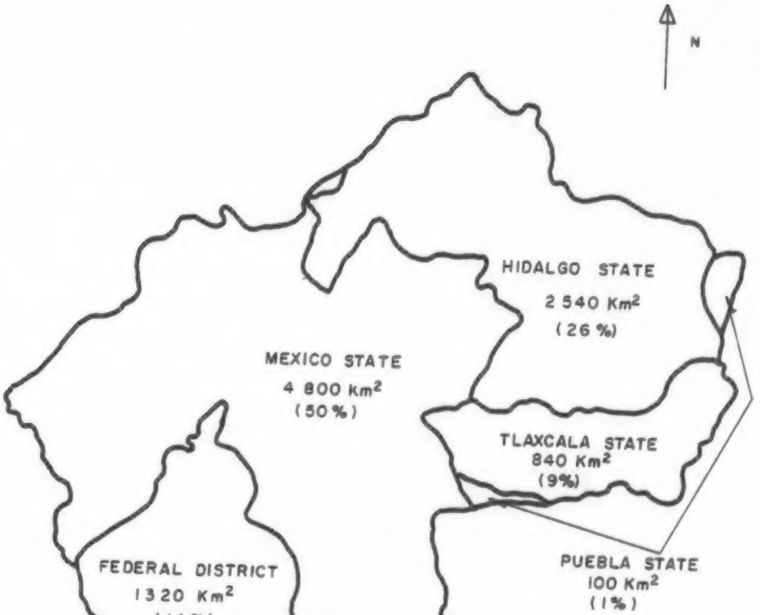

N
HIDALGO STATE
2 540 Km^2
(26 %)
MEXICO STATE
4 800 Km^2
(50 %)
TLAXCALA STATE
840 Km^2
(9%)
FEDERAL DISTRICT
1320 Km^2
(14 %)
PUEBLA STATE
100 Km^2
(1%)

FIGURE 1 VALLEY OF MEXICO-POLITICAL DISTRIBUTION

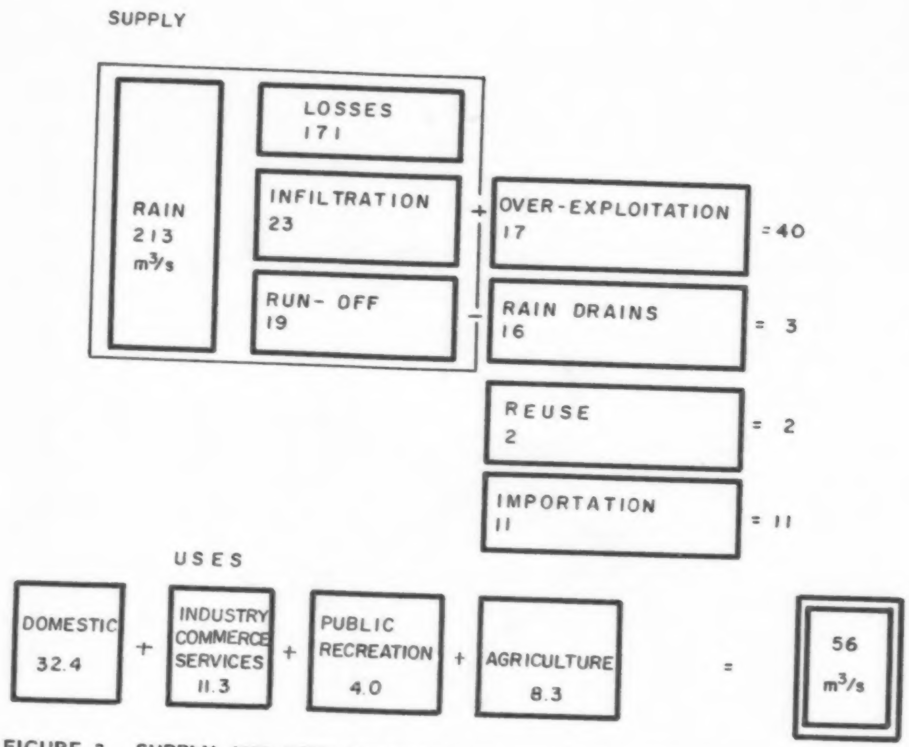
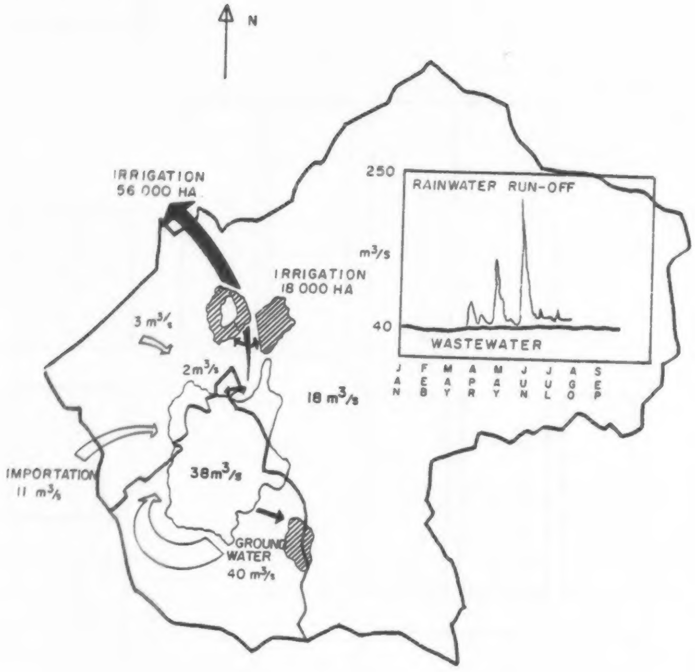
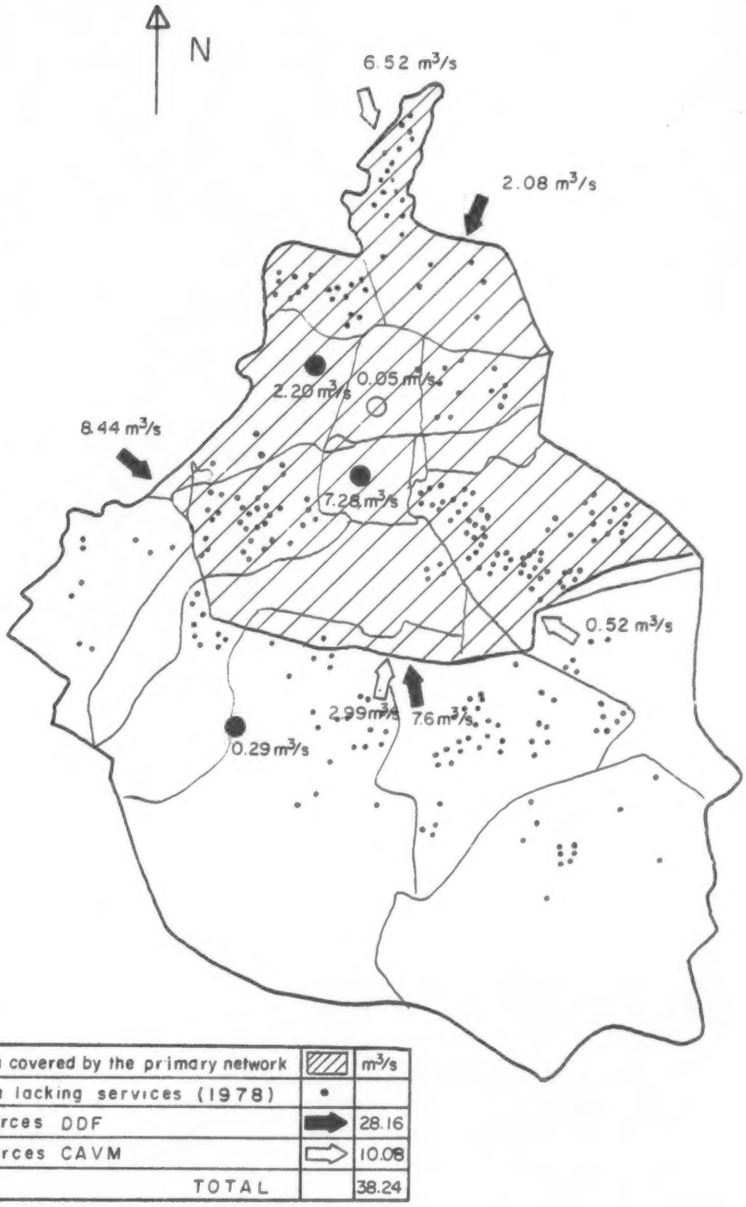

SUPPLY
RAIN 213 m³/s
LOSSES 171
INFILTRATION 23
RUN- OFF 19
+
−
OVER-EXPLOITATION 17
= 40
RAIN DRAINS 16
= 3
REUSE 2
= 2
IMPORTATION 11
= 11
USES
DOMESTIC 32.4
+
INDUSTRY COMMERCE SERVICES 11.3
+
PUBLIC RECREATION 4.0
+
AGRICULTURE 8.3
=
56 m³/s

FIGURE 2 SUPPLY AND USES OF WATER IN THE VALLEY OF MEXICO



N
IRRIGATION
56 000 HA
IRRIGATION
18 000 HA
3 m³/s
2m³/s
18 m³/s
IMPORTATION
11 m³/s
38m³/s
GROUND WATER
40 m³/s
250
RAINWATER RUN-OFF
m³/s
40
WASTEWATER
JAN
FEB
MAY
APR
MAY
JUN
JUL
AGO
SEP

FIGURE 3 HYDROLOGICAL BALANCE IN THE VALLEY OF MEXICO


N
6.52 m3/s
2.08 m3/s
2.20 m3/s
0.05 m3/s
8.44 m3/s
7.28 m3/s
0.52 m3/s
2.99 m3/s
7.6 m3/s
0.29 m3/s

Area covered by the primary network	▨	m³/s
Area lacking services (1978)	•	
Sources DDF	➡	28.16
Sources CAVM	⇨	10.08
TOTAL		38.24

FIGURE 4 PRESENT POTABLE WATER SYSTEM

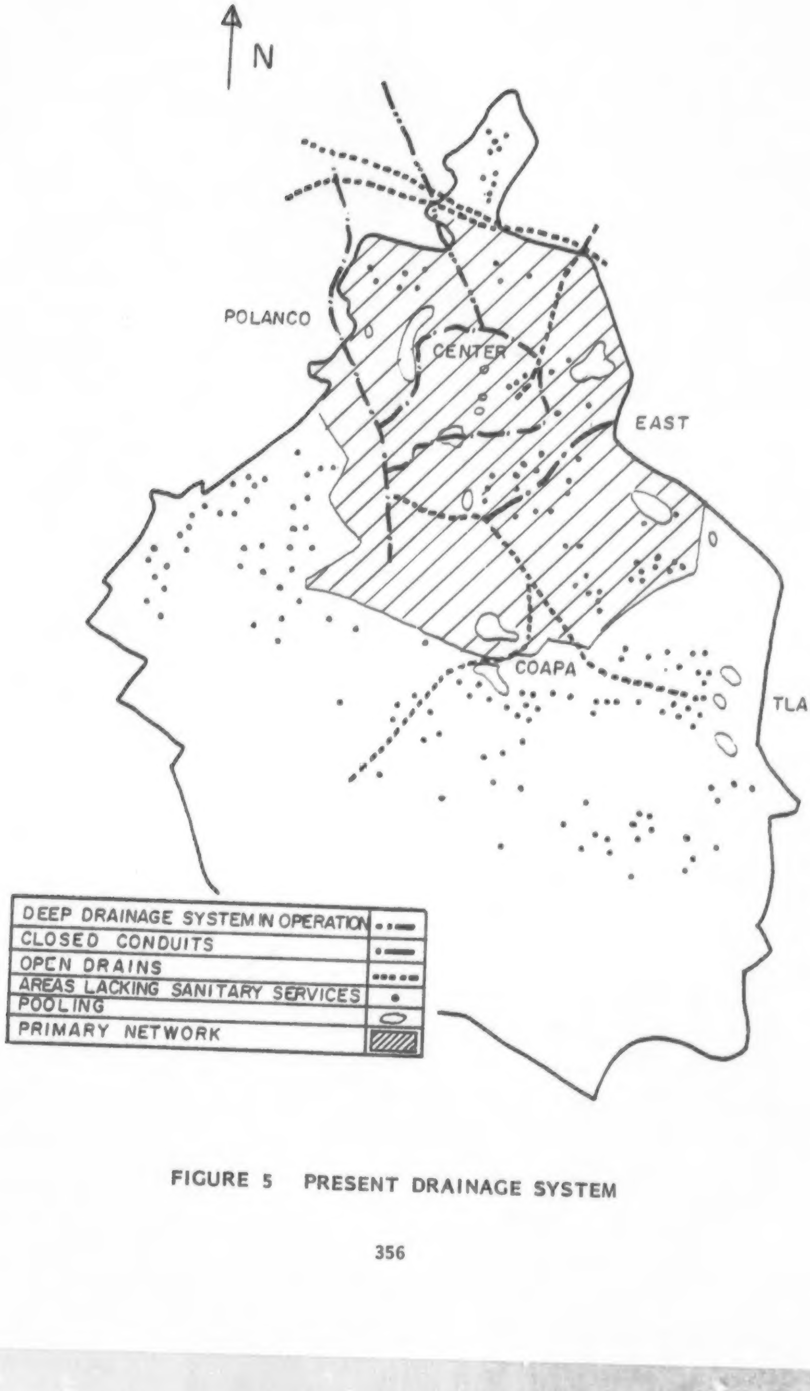

N
POLANCO
CENTER
EAST
COAPA
TLAHUAC
DEEP DRAINAGE SYSTEM IN OPERATION
CLOSED CONDUITS
OPEN DRAINS
AREAS LACKING SANITARY SERVICES
POOLING
PRIMARY NETWORK

FIGURE 5 PRESENT DRAINAGE SYSTEM

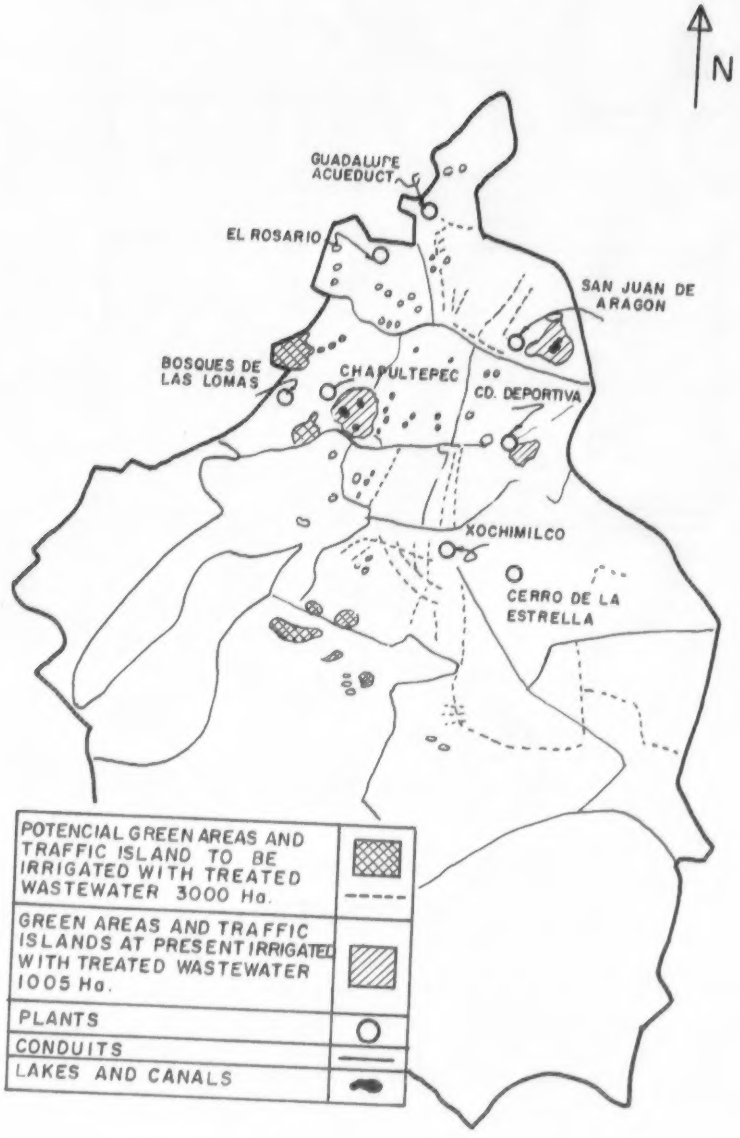

N
GUADALUPE ACUEDUCT
EL ROSARIO
SAN JUAN DE ARAGON
BOSQUES DE LAS LOMAS
CHAPULTEPEC
CD. DEPORTIVA
XOCHIMILCO
CERRO DE LA ESTRELLA
POTENCIAL GREEN AREAS AND TRAFFIC ISLAND TO BE IRRIGATED WITH TREATED WASTEWATER 3000 Ha.
GREEN AREAS AND TRAFFIC ISLANDS AT PRESENT IRRIGATED WITH TREATED WASTEWATER 1005 Ha.
PLANTS
CONDUITS
LAKES AND CANALS

FIGURE 6 PRESENT TREATMENT PLANT SYSTEM

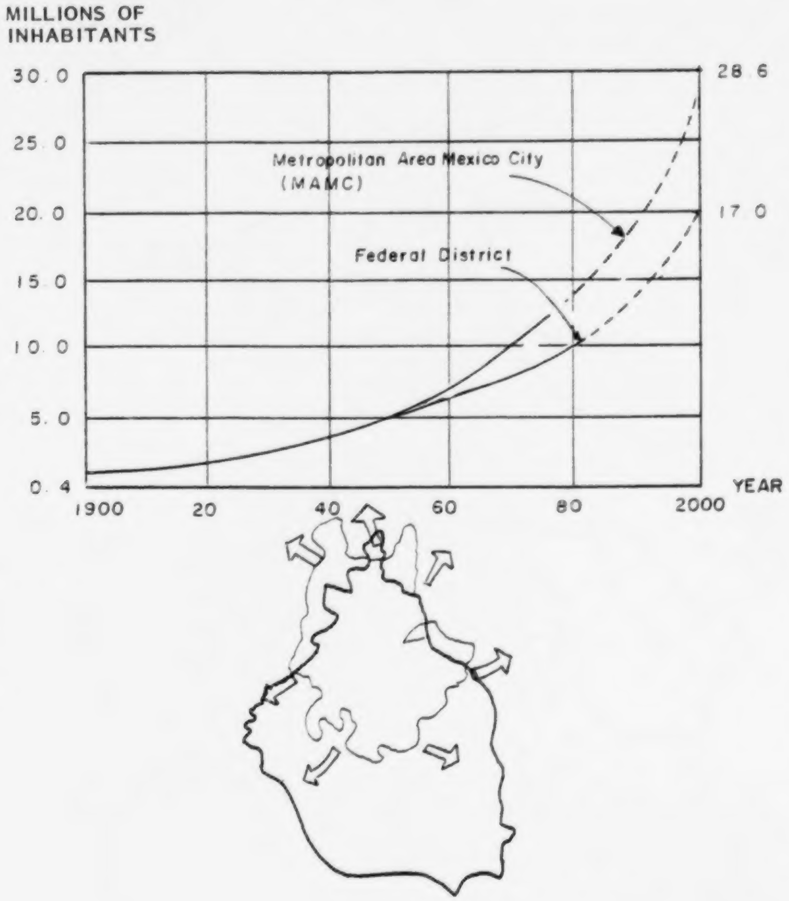


FIGURE 7 POPULATION GROWTH

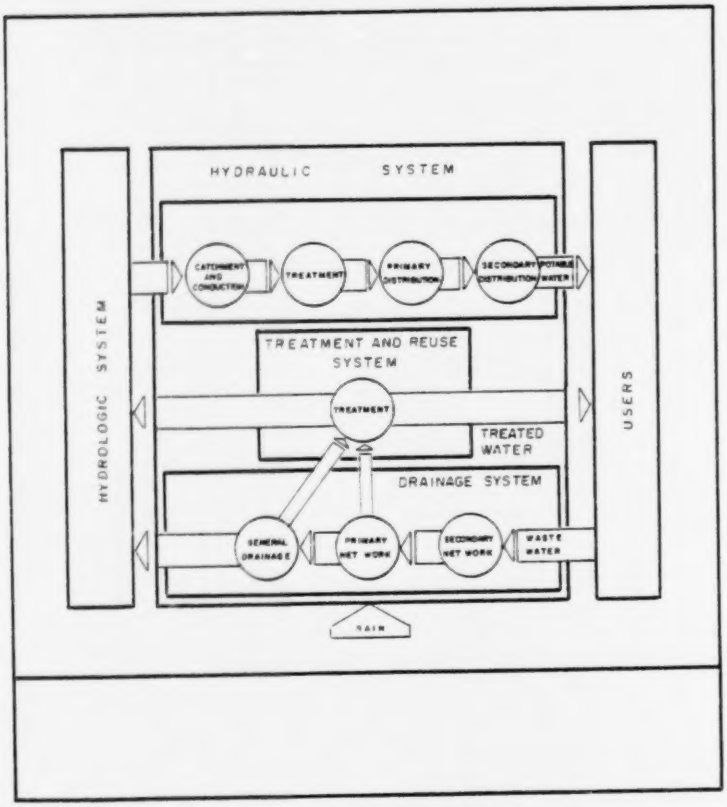

HYDRAULIC SYSTEM
HYDROLOGIC SYSTEM
CATCHMENT AND CONDUCTION
TREATMENT
PRIMARY DISTRIBUTION
SECONDARY DISTRIBUTION
POTABLE WATER
TREATMENT AND REUSE SYSTEM
TREATMENT
TREATED WATER
USERS
DRAINAGE SYSTEM
GENERAL DRAINAGE
PRIMARY NET WORK
SECONDARY NET WORK
WASTE WATER
RAIN

FIGURE 8 FEDERAL DISTRICT'S HYDRAULIC SYSTEM

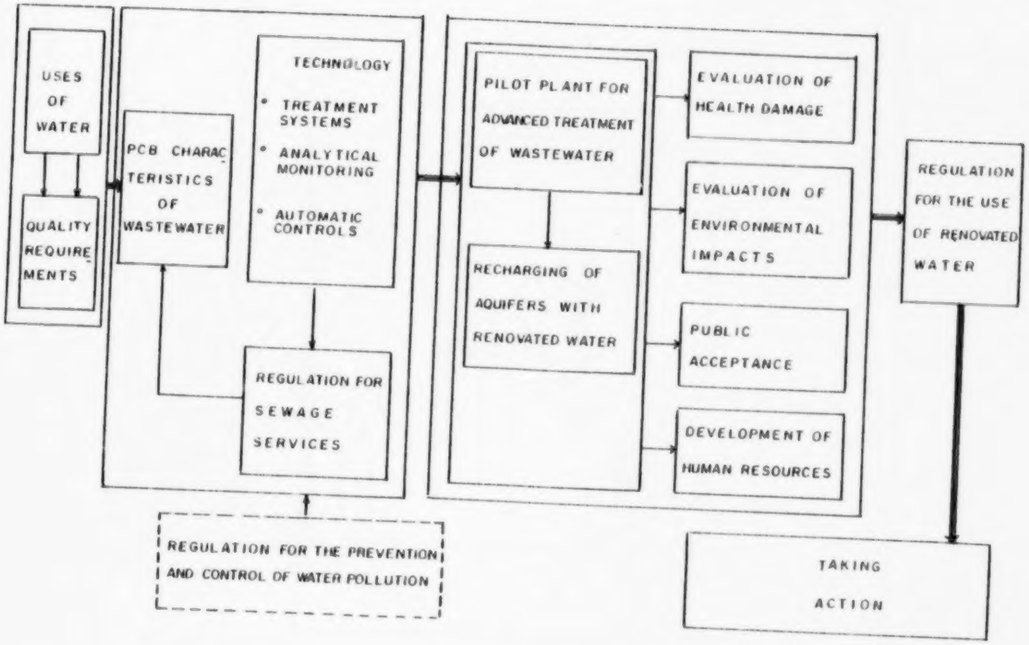

USES OF WATER
QUALITY REQUIREMENTS
PCB CHARACTERISTICS OF WASTEWATER
TECHNOLOGY
• TREATMENT SYSTEMS
• ANALYTICAL MONITORING
• AUTOMATIC CONTROLS
REGULATION FOR SEWAGE SERVICES
REGULATION FOR THE PREVENTION AND CONTROL OF WATER POLLUTION
PILOT PLANT FOR ADVANCED TREATMENT OF WASTEWATER
RECHARGING OF AQUIFERS WITH RENOVATED WATER
EVALUATION OF HEALTH DAMAGE
EVALUATION OF ENVIRONMENTAL IMPACTS
PUBLIC ACCEPTANCE
DEVELOPMENT OF HUMAN RESOURCES
REGULATION FOR THE USE OF RENOVATED WATER
TAKING ACTION

FIGURE 9 INTER-RELATIONSHIP BETWEEN BASIC STUDIES

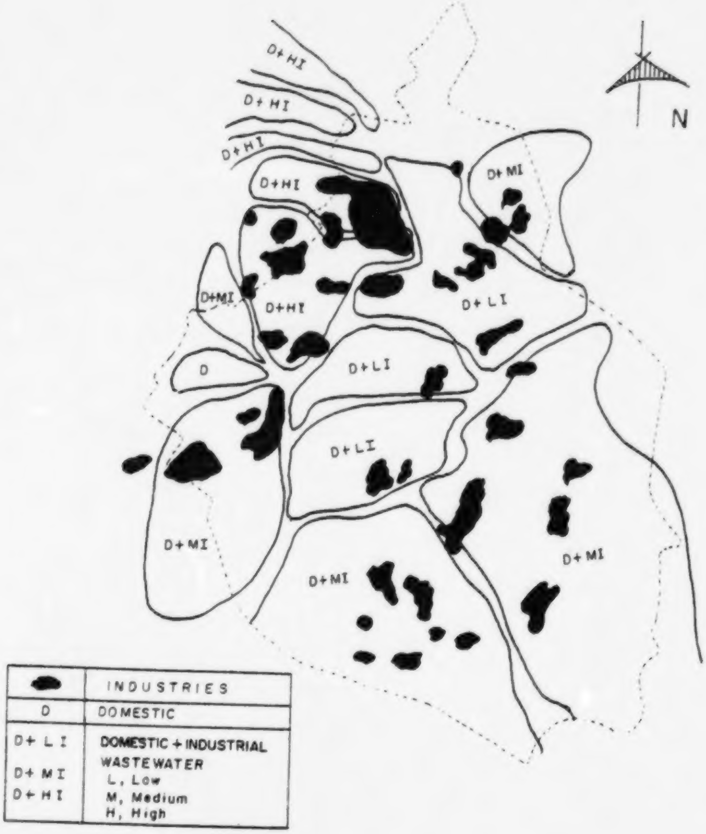

N
D+HI
D+HI
D+HI
D+HI
D+MI
D+MI
D+HI
D+LI
D
D+LI
D+LI
D+MI
D+MI
D+MI
INDUSTRIES
D
DOMESTIC
D+LI
D+MI
D+HI
DOMESTIC + INDUSTRIAL WASTEWATER
L, Low
M, Medium
H, High

FIGURE 10 CITY AREAS ACCORDING TO PCB QUALITY OF WASTEWATER

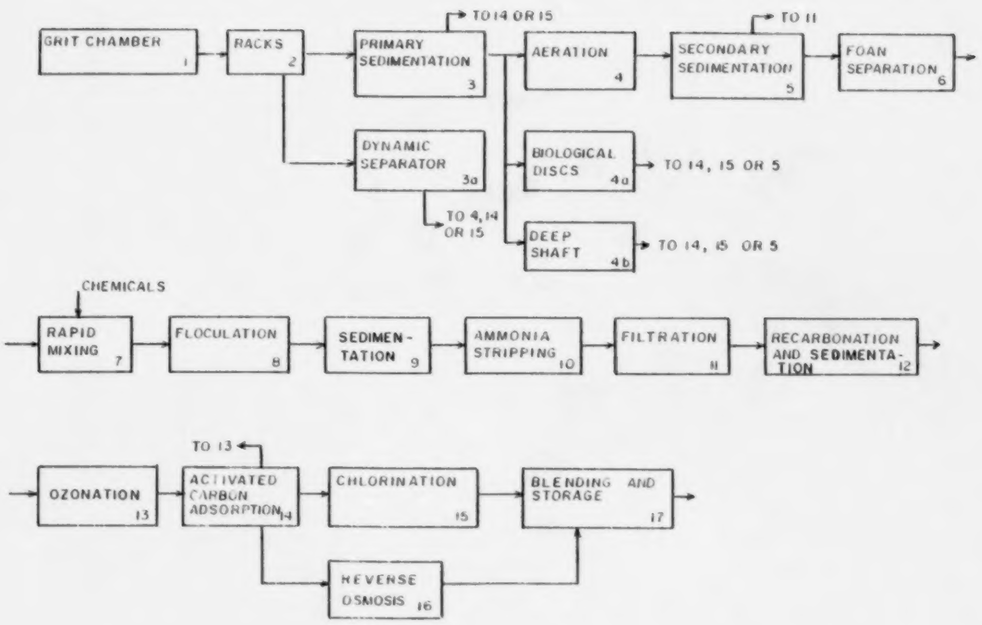
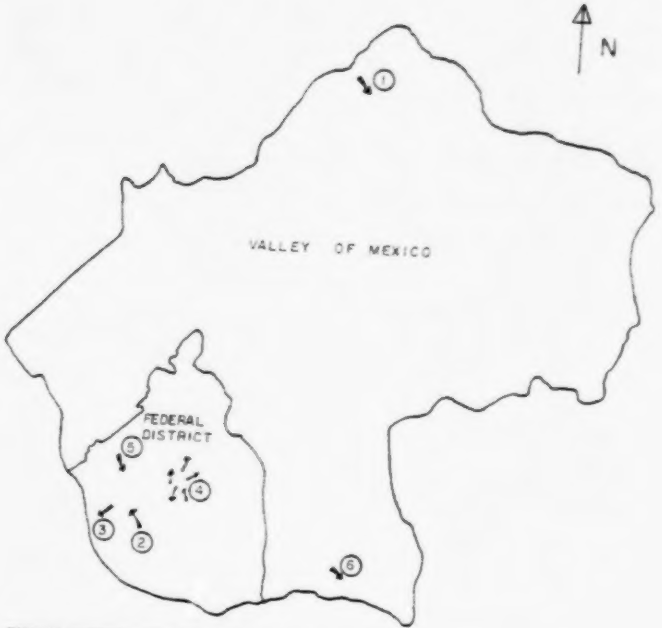

GRIT CHAMBER 1
RACKS 2
PRIMARY SEDIMENTATION 3
TO 14 OR 15
DYNAMIC SEPARATOR 3a
TO 4, 14 OR 15
AERATION 4
BIOLOGICAL DISCS 4a
TO 14, 15 OR 5
DEEP SHAFT 4b
TO 14, 15 OR 5
SECONDARY SEDIMENTATION 5
TO 11
FOAN SEPARATION 6
CHEMICALS
RAPID MIXING 7
FLOCULATION 8
SEDIMENTATION 9
AMMONIA STRIPPING 10
FILTRATION 11
RECARBONATION AND SEDIMENTATION 12
OZONATION 13
TO 13
ACTIVATED CARBON ADSORPTION 14
CHLORINATION 15
REVERSE OSMOSIS 16
BLENDING AND STORAGE 17

FIGURE 11 PILOT PLANT FLOW DIAGRAM


N
VALLEY OF MEXICO
FEDERAL DISTRICT
1
2
3
4
5
6

Nº	SITE	INFILTRATION OF		CANCELED BY
		WASTEWATER	RAIN	
1	Pachuca	●		Urban growth
2	Pedregal		●	Urban growth
3	Xictli		●	In operation
4	Mexico City		●	Urban growth
5	Mixcoac		●	Pollution
6	Peaje		●	Pollution

FIGURE 12 EXPERIENCES IN AQUIFER RECHARGE IN THE VALLEY OF MEXICO

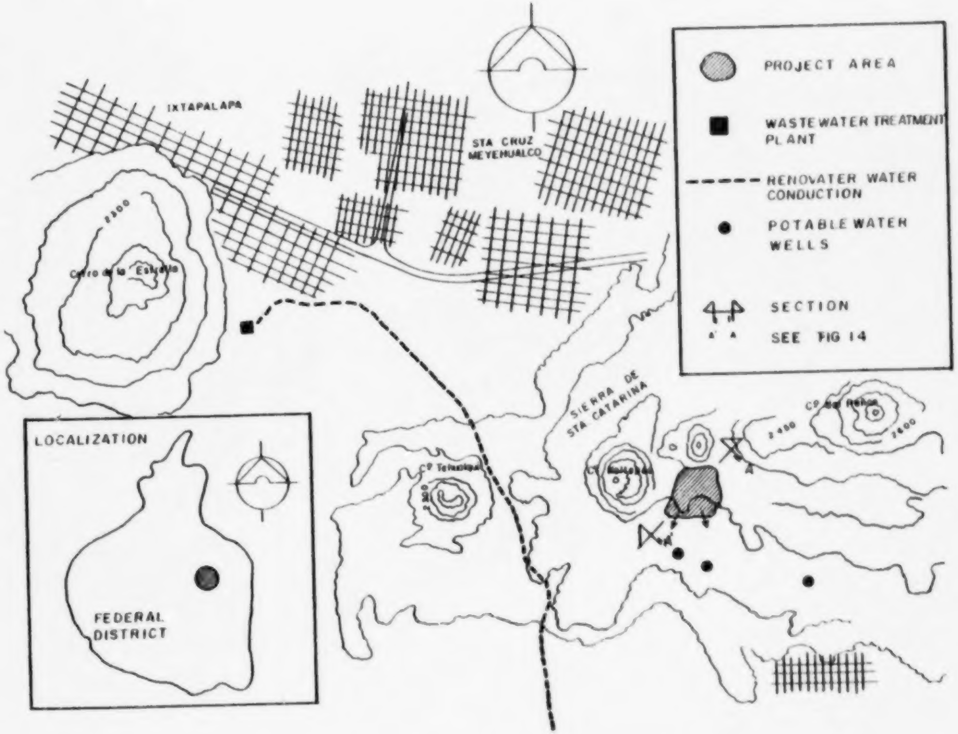

IXTAPALAPA
STA CRUZ MEYEHUALCO
Cerro de la Estrella
2300
SIERRA DE STA CATARINA
2400
2400
A
A'
LOCALIZATION
FEDERAL DISTRICT
PROJECT AREA
WASTEWATER TREATMENT PLANT
RENOVATER WATER CONDUCTION
POTABLE WATER WELLS
SECTION
A' A
SEE FIG 14

FIGURE 13 AQUIFER RECHARGE - DEMONSTRATION PROJECT

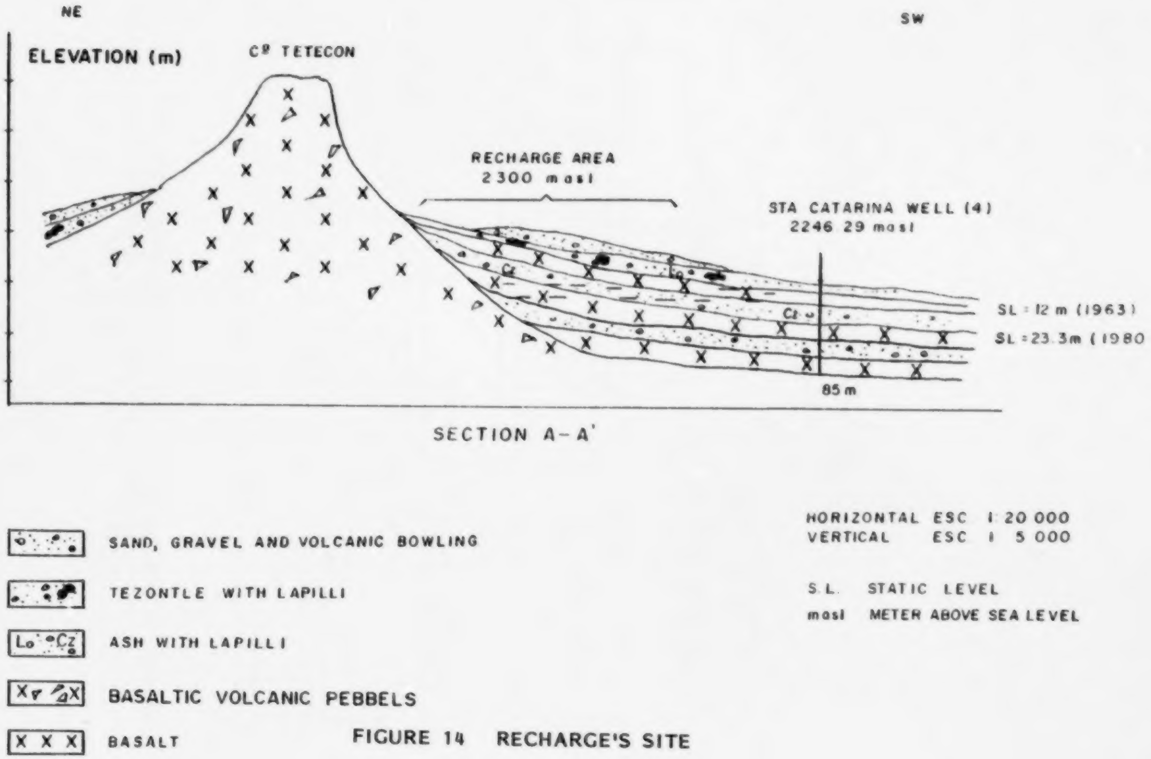

NE
SW
ELEVATION (m)
Cº TETECON
2450
2400
2350
2300
2250
2200
2150
RECHARGE AREA
2300 masl
STA CATARINA WELL (4)
2246 29 masl
SL = 12 m (1963)
SL = 23.3m (1980
85 m
SECTION A-A'
SAND, GRAVEL AND VOLCANIC BOWLING
TEZONTLE WITH LAPILLI
ASH WITH LAPILLI
BASALTIC VOLCANIC PEBBELS
BASALT
HORIZONTAL ESC 1:20 000
VERTICAL ESC 1 5 000
S.L. STATIC LEVEL
masl METER ABOVE SEA LEVEL

FIGURE 14 RECHARGE'S SITE

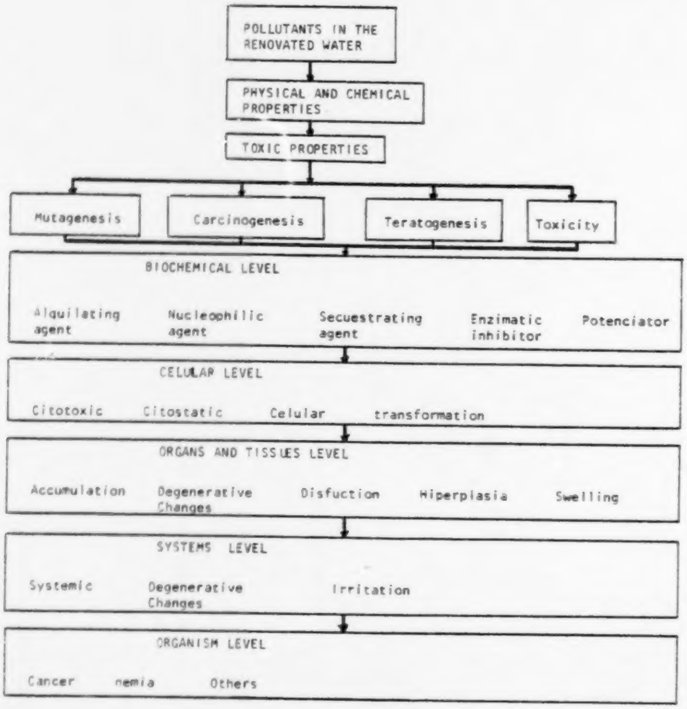

POLLUTANTS IN THE RENOVATED WATER
PHYSICAL AND CHEMICAL PROPERTIES
TOXIC PROPERTIES
Mutagenesis
Carcinogenesis
Teratogenesis
Toxicity
BIOCHEMICAL LEVEL
Alquilating agent
Nucleophilic agent
Secuestrating agent
Enzimatic inhibitor
Potenciator
CELULAR LEVEL
Citotoxic
Citostatic
Celular
transformation
ORGANS AND TISSUES LEVEL
Accumulation
Degenerative Changes
Disfuction
Hiperplasia
Swelling
SYSTEMS LEVEL
Systemic
Degenerative Changes
Irritation
ORGANISM LEVEL
Cancer
nemia
Others

FIGURE 15 METHODOLOGY FOR THE DETERMINATION OF THE TOXIC EFFECTS RESULTING FROM THE POLLUTANTS PRESENT IN RENOVATED WATER

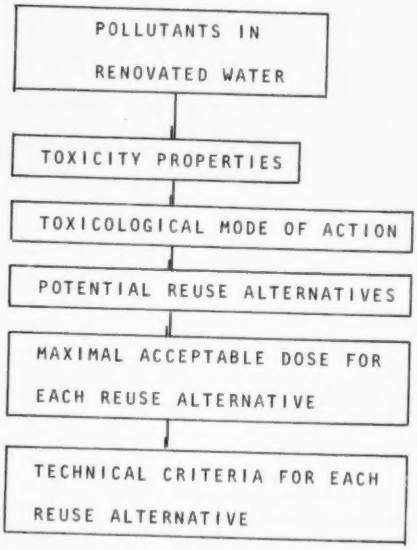

POLLUTANTS IN RENOVATED WATER
TOXICITY PROPERTIES
TOXICOLOGICAL MODE OF ACTION
POTENTIAL REUSE ALTERNATIVES
MAXIMAL ACCEPTABLE DOSE FOR EACH REUSE ALTERNATIVE
TECHNICAL CRITERIA FOR EACH REUSE ALTERNATIVE

FIGURE 16 METHODOLOGY FOR THE SELECTION OF QUALITY CRITERIA BASED ON TOXIC PROPERTIES OF POLLUTANTS PRESENT IN RENOVATED WATERS

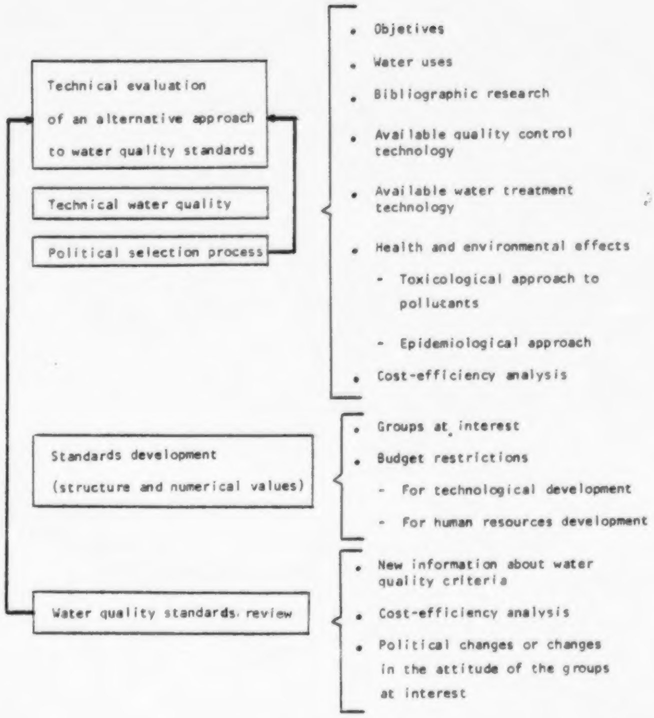

Technical evaluation of an alternative approach to water quality standards
Technical water quality
Political selection process
Objetives
Water uses
Bibliographic research
Available quality control technology
Available water treatment technology
Health and environmental effects
- Toxicological approach to pollutants
- Epidemiological approach
Cost-efficiency analysis
Standards development (structure and numerical values)
Groups at interest
Budget restrictions
- For technological development
- For human resources development
Water quality standards review
New information about water quality criteria
Cost-efficiency analysis
Political changes or changes in the attitude of the groups at interest

FIGURE 17 METHODOLOGY TO FOLLOW ON THE DEVELOPMENT OF PHYSICAL, CHEMICAL, AND BIOLOGICAL QUALITY CRITERIA OF RENOVATED WATER

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WASTEWATER RECLAMATION AT JEDDAH AND MECCA, SAUDI ARABIA

J. Edward Singley, Ph.D.,
Timothy P. Brodeur,
Charles W. Dougherty, and
Bevin A. Beaudet, P.E.
Environmental Science and Engineering, Inc.
P.O. Box ESE
Gainesville, Florida 32602

INTRODUCTION

Few areas in the world have a greater need for a lasting supply of fresh water than Jeddah and Mecca, Saudi Arabia.

The City of Jeddah, located on the Red Sea, has a history of a shortage of potable drinking water due to the combination of low rainfall, saline ground water, and lack of a river supply from the mountains to the east.

Until approximately 30 years ago, much of the water for Jeddah was supplied by camel trains which brought this precious commodity to the city from shallow wells located many kilometers inland beyond the reach of the salinity from the Red Sea. A small seawater distillation plant augmented this water supply. The water supply for Jeddah increased dramatically by the installation of a pipeline from Wadi Fatimah, followed a few years later by the discovery of water and installation of a pipeline to Wadi Khulays. These two sources of water served well for approximately 20 years, but the Wadi Khulays supply has become increasingly saline over the years.

Approximately 10 years ago, a program was launched to meet the increasing needs for potable drinking water in Jeddah by the use of seawater distillation plants. The first such plant had a rated capacity of 19,000 cubic meters (m^3)/day [5 million gallons per day (MGD)], the second had a capacity of 38,000 m^3/day (10 MGD), and the third stage included the recent completion of a 76,000-m^3/day (20-MGD) desalination facility. An additional 190,000-m^3/day (50-MGD) desalination plant is under construction and is expected to be completed within the next year.

When the Stage 4 desalination plant begins operating, the total water supply available to the City of Jeddah will be from 300,000 to 400,000 m^3/day. This capacity will supply the city with drinking water for many years to come, but because of the dry climate and large area of metropolitan Jeddah, water shortages for such uses as beautification, industrial use, and agricultural irrigation will continue. The water supply will have to be expanded in order to meet the demands of a growing population. The average per-capita use is slightly more than 100 liters per day, based on an estimated population of 1,200,000 people. It is expected that in the near future, per-capita use will range from 400 to 500 liters per day, the general average in highly developed societies. A predicted population of 2.25 million by the year 2000 would consume approximately 1,000,000 m^3/day.

The City of Mecca also suffers from a lack of potable drinking water due to the absence of an easily accessible surface supply or readily tapped groundwater reserve.

Water for Mecca is currently obtained from the reserves found in the Wadi Fatimah Basin and the Wadi Na'man Basin. Much of the water is supplied by pipelines connecting each of the basins with the city. Increased demands exerted on the groundwater reserves by the population of Mecca, as well as by many other neighboring cities, have caused water to be drawn from the aquifer at a rate greater than that which can be recharged through natural groundwater replenishment. This, in turn, led to decreased water quality.

The water supply to Mecca should be augmented within the near future by a well expected to produce approximately 15,000 m^3/day. In addition, a 19,000-m^3/day (5-MGD) desalination plant to be located on the shore in the Sheoba zone is also being studied. A pipeline will connect the plant with the city. These two water sources should alleviate many drinking water supply problems, but because of the dry climate and large area of metropolitan Mecca, water shortages for nonpotable uses will continue. Much of this water can be supplied by renovating the wastewaters of Mecca and using them for beneficial purposes.

In mid-1979, Russell and Axon International Engineers-Architects, Ltd. and Consulting Engineers Office, with ESE as subcontractor, were awarded a contract from the Water and Sewage Department for the Western Region, Saudi Arabia. They were contracted to conduct a feasibility study to use treated wastewater as a raw water source for a secondary water supply in the cities of Jeddah and Mecca. The purpose of the study was to determine the uses for the renovated waters, the water quality required for each use, and the treatment methods of a proposed first-phase water renovation facility.

Because water renovation and reuse is being practiced in several Moslem countries, a meeting in early 1979 of leaders of the Moslem faith was held to study the concept of reusing wastewater with respect to the teachings of the Koran and Islamic religious principles. As a result, a resolution was issued declaring reuse of wastewaters after treatment to be compatible with Islamic precepts provided that the treated water was odorless, clear, colorless, and tasteless.

RENOVATED WATER QUALITY GOALS

Production of a renovated water which meets the stringent Islamic guidelines can best be accomplished by establishing quality criteria that assure that the water can be used for any purpose. Because the greatest use of water is domestic consumption, these criteria were chosen for the study. Although it was recognized that the final end use of this water would not be domestic consumption, these criteria most closely approximate the clear, colorless, tasteless, and odorless requirements of the Islamic ruling. The most probable use of the water produced by the initial phase of wastewater renovation projects will be for irrigating parks, medians, greenbelts, and landscaping, as well as truck crops. Truck crops which are consumed uncooked should be irrigated with water that also meets the religious criteria.

There have been several recognized sets of such drinking water criteria used by different agencies. Among the best established criteria are those of the World Health Organization (WHO) (1970, 1971) and the United

States Environmental Protection Agency (EPA) (1976). These criteria are listed in Table 1. Those shown as WHO criteria are those that were used as the basis of the process design.

PROCESS DESIGN

Basic Guidelines

The basic guidelines established for the treatment processes were to:

1. Meet the Islamic requirement for clear, odorless, colorless, and tasteless water;
2. Use the minimum treatment necessary to provide a water of acceptable quality;
3. Provide a facility that would be simple to operate and have minimum maintenance requirements;
4. Choose an alternative with the minimum capital cost;
5. Use readily available chemicals for treatment; and
6. Design each renovation facility for 50,000 m^3/day flow.

Sources and Quality of Water for Renovation

The sources of water for these projects are the wastewater effluents from the Jeddah and Mecca Sewage (Wastewater) Treatment Plants, respectively. These 6-year-old trickling filter plants have a design capacity of 50,000 m^3/day each and the following main treatment elements.

1. Pretreatment,
    a. Bar screens (4), and
    b. Barminutors (2);
2. Aerated grit removal;
3. Primary settling (2);
4. Trickling filters (4) with rock media;
5. Secondary settling (humus) (2);
6. Anaerobic digestion (2); and
7. Chlorination and metering.

Each plant additionally has room at its site for ultimate expansion to 100,000 m^3/day.

Table 2 presents a summary of critical design parameters from the effluent of each plant. These data represent an average of 12 months of operating data. Jeddah plant effluent is characterized by high total dissolved solids (TDS), salinity, and hardness, due primarily to significant groundwater infiltration and the practice of construction contractors discharging to the city sewer system during site dewatering operations. These conditions imposed additional constraints on the process design in that the unit processes had to function effectively and predictably under these unusual conditions.

Selection Criteria for Treatment Unit Processes

The approach used in developing a process train was to evaluate individual unit processes and then assemble them into an overall process that would meet the established water quality criteria as well as the other requirements of the relevant authorities.

Those unit processes chosen for consideration were processes which are well established in practice, easy to operate, effective, reliable, and easy to implement. Although there are many physical and/or physical/chemical treatment processes which have been proposed on an experimental basis for modification of specific water quality parameters, they have not been considered here because of the lack of operational information upon which to base realistic expectations of their performance. In addition, their inclusion is not necessary because a high quality treated water can be produced using accepted unit processes.

Each candidate unit process was considered in terms of its effect on relevant water quality parameters, reliability, ease of implementation, and operational simplicity.

Effect of Unit Processes on Water Quality

In order to assemble the optimum overall process, the effect of competitive unit processes was based on the water quality that would probably be available at that point in the process train. For example, it is obvious that normal primary and secondary wastewater treatment, as currently practiced, would be the first step in the process and should be optimized. Another logical sequence is to place pretreatment ahead of the demineralization step at Jeddah. Other such choices were made based on the experience of the design team.

The following discussions of the various water reuse unit processes are based upon average performance for conventional domestic wastewater influent quality. Table 3 is presented to illustrate the average characteristics of 14 plants used by the United States Department of the Interior (1979) in their analysis of wastewater reuse.

In order to evaluate the specific effect of the various unit treatment processes on contaminant levels, it is useful to have a generalized idea of the effect to be expected from these processes. These comparisons are presented in Table 4 as determined by experience with many treatment plants.

Candidate Unit Processes

Optimization of Current Plant Processes. The current treatment process will be discussed in terms of individual unit processes in order to evaluate its potential for optimization. In that case, one factor that could distort the comparison with conventional unit processes in other plants is the high TDS and salinity of Jeddah wastewater. Fortunately, data are available from treatment plants with raw water quality similar to the waters at Jeddah and Mecca. A study at San Francisco, California, USA, included three plants which had waters with TDS averaging approximately 500 milligrams per liter (mg/l), approximately 1,900 mg/l (similar to Mecca wastewater), and greater than 5,000 mg/l (similar to Jeddah wastewater), respectively. The complete analyses are shown in Table 5. These are average values as reported by the United States Department of the Interior (1979). It is noted that wastes with salinity of greater than 5,000 mg/l responded satisfactorily to biological treatment.

Primary treatment includes bar screens, barminutors, aerated grit removal, and primary settling. The process requires little operator control and is, therefore, relatively consistent in performance. The typical effect on relevant water quality parameters is shown in Table 6. The columns identified as A and B are from the same San Francisco plants used in Table 5. Source A compares to the water quality at Mecca and Source B to Jeddah. Figures 1 and 2 show the specific effect to be expected for Jeddah and Mecca, where the influent quality data have been normalized to 100 percent. The numbers above the figure are the initial concentrations and those above a bar represent typical values to be expected.

Even though trickling filters are a simple secondary treatment process, they are subject to upset due to flow variation. The suspended solids content of the effluent is dependent upon satisfactory secondary sedimentation. Temperature also has a significant effect on performance as higher temperatures increase biological activity.

Trickling filters are relatively effective for removal of all classes of organics in wastewater but are relatively ineffective for removal of any inorganic ions. The data are shown in Table 7. Figures 3 and 4 show the effect of trickling filters on Jeddah and Mecca water quality, based on primary treatment followed by trickling filters, with the current plant operation optimized in order to obtain results equal to the average expected in the United States.

Coagulation-Sedimentation. The coagulation-sedimentation process is complex with many variables affecting the results. There are many coagulants and coagulant aids available for use, each having its own area of effectiveness, depending on the influent quality and the effluent critiera. The only coagulant considered was alum (aluminum sulfate), as it is the most common coagulant worldwide and thus most readily available. The use of ferric salts produces approximately the same results as alum. The choice between the two would be based on local availability and cost. The equipment required is the same for either coagulant.

There is considerable variation in results obtained in coagulation-sedimentation processes because of the complex nature of the process and the influence of many chemical factors as well as the heavy dependence upon operation. The coagulant feed systems, any necessary pH control chemicals, and the physical operating variables require constant attention in order to maintain optimum treatment. If conditions are allowed to vary significantly from those for optimum treatment, the effluent quality may degrade dramatically.

The coagulation-sedimentation process is effective for the removal of suspended solids as well as many different metal ions. The percentage removal for the same two plants, A and B, from the San Francisco study are shown along with some literature results in Table 8. Figures 5 and 6 show the effect of alum coagulation-sedimentation on primary effluent.

Softening. Lime or a combination of lime and soda ash can be added to a water for removal of contaminants such as calcium, heavy metal ions, solids, and organics. The process involves equipment similar to the coagulation-sedimentation process above. The soda ash and/or lime must be added in sufficient quantity to raise the pH to a point where calcium carbonate ($CaCO_3$) and possibly magnesium hydroxide precipitate. This pH is usually greater than 9.5 and thus many metal ions co-precipitate as the hydroxides. The mass of heavy floc adsorbs soluble organic compounds, and the polymeric or metal ion coagulants used result in simultaneous precipitation of suspended solids. Softening is frequently followed by acid addition for pH reduction using either a mineral acid or carbon dioxide (CO_2).

The site-specific nature of softening makes it mandatory that each water supply be considered separately. The Jeddah and Mecca wastewaters are characterized by very high hardness and low alkalinity. This means that only a limited amount of softening can be accomplished using lime alone. Additional softening can be accomplished using soda ash, but this increases TDS, because it effectively replaces each calcium (at. wt. 40) with two sodiums (at. wt. 23) or an additional 6 mg/l dissolved solids for each 100 mg/l of hardness removed.

This process is subject to the same operating problems as the coagulation-sedimentation process using alum or iron salts because the chemical feed control and other operating variables must be monitored closely in order to optimize treatment.

Table 9 shows the general results of softening with lime on a number of relevant water quality parameters. As pointed out above, lime is effective for removal of many metal ions and is particularly effective for removing phosphorus. Because data were not available for the use of lime softening following alum coagulation-sedimentation, data for iron coagulation-sedimentation were used. The use of either coagulant prior to lime softening is comparable. Figures 7 and 8 show the effect of lime softening on the water quality parameters at Jeddah and Mecca.

Recarbonation. Recarbonation is the addition of CO_2 to a high pH water in order to reduce the pH and consequently reduce the tendency for $CaCO_3$ to deposit on any surface in contact with the water. Recarbonation usually follows a process in which lime is used as a precipitant. The source of CO_2 can be stack gas from burning any fuel, liquid CO_2, recalcination of $CaCO_3$ sludge, or on-site combustion of fuel specifically for CO_2 production. The reduction of pH can be accomplished by use of any acid with the choice usually favoring CO_2 because of economics. Large plants may find it economical to recalcine lime from sludges and use the evolved CO_2 for recarbonation.

Recarbonation has essentially no effect on the removal of contaminants. Its only function is the reduction of pH. The simplicity of this process assures its reliability.

Filtration. Filtration is the process whereby treated water is passed through a granular medium in a bed. It may be accomplished either by gravity flow or under pressure. The most common medium is sand, although many other materials have been utilized. The influent can be pretreated by primary sedimentation, secondary treatment, coagulation-sedimentation, or softening. In any event, the quality of the filtrate is directly proportional to the efficiency of the pretreatment process or processes. The principal role of filtration is the removal of suspended solids and the removal of colloidal particulates such as bacteria and virus. It has been shown that multi-media filtration can remove up to 99 percent of virus when supplemented with the pre-feed of a polymer, and it is well known that filtration with good pretreatment can remove 99+ percent of bacteria.

Filtration is a relatively simple process to operate but requires some operation attention. Backwash can be automated, but with variable influent quality possible from the pretreatment processes, it is desirable to base backwash upon filter effluent monitoring.

As pointed out above, the effectiveness of filtration is dictated by the pretreatment. Filter design also must be appropriate to the quality of influent expected. Conventionally, filtration alone, assuming good pretreatment, can be expected to produce an effluent with 6 to 15 mg/l suspended solids from two-stage trickling filter pretreatment and 10 to 20 mg/l from high-rate trickling filters. Polymer pre-feed may improve these values appreciably. Biological oxygen demand (BOD) reductions of 60 to 93 percent and total suspended solids reductions of 37 to 95 percent are reported in the literature for the use of filtration alone following biological secondary treatment, with no chemical additions. Little effect is expected for the other parameters of concern.

The removal of pathogens is directly proportional to the removal of suspended solids, as shown in Figure 9.

Demineralization. There are four principal unit processes for demineralization of water--distillation, ion exchange, electrodialysis, and reverse osmosis. Distillation and ion exchange are normally much too expensive to be considered for wastewater renovation. In addition, major problems have been encountered for both processes from organic fouling. Electrodialysis has not been able to compete economically with reverse osmosis up to the present time. For these reasons, reverse osmosis is the only demineralization that has been considered for inclusion in the process stream.

The operation of a reverse osmosis unit requires more mechanical aptitude than most wastewater processes. There are relatively few chemical factors and essentially no biological factors involved in operation. The major problems result from membrane fouling from organics and precipitated salts. Pretreatment effectiveness can eliminate the problems and guarantee reliable performance of the reverse osmosis unit.

Typical results for removal of contaminants from wastewaters with different pretreatment processes are shown in Table 10. These results dramatically illustrate the effectiveness for removal of ionic contaminants as well as the removal of some organic compounds which constitute part of the chemical oxygen demand (COD). The lighter organic compounds are not removed by reverse osmosis. Figure 10 shows the effect of reverse osmosis on the average trickling filter effluent from Jeddah. Reverse osmosis was not considered necessary for treatment at Mecca.

Disinfection. There are at least three disinfectants that have been used to provide a water safe for human consumption--chlorine, ozone, and CO_2. Chlorine is the simplest to feed as it can be provided as a gas for dissolution in water or as a sodium or calcium salt. The equipment is relatively simple but safety precautions in design and operation are very important when using gaseous chlorine. The capital cost is small but the operational costs may be high. In contrast, ozone must be generated on site with high capital cost and operations costs dependent on power rates. Ozone has the advantage over chlorine of being a better disinfectant for both viruses and bacteria at shorter contact times. It is also a better oxidant for organics and ammonia nitrogen, which it oxidizes to nitrate.

CO_2 is a very effective disinfectant and oxidant but is expensive to generate, requiring gaseous chlorine and sodium chlorite. For this reason, CO_2 will not be considered here.

As stated above, chlorine is fed as a solution of the gas in water or a solution of the sodium or calcium salt. It has the advantage of having an easily-monitored residual in the water. Objections to the taste of chlorine or chlorinated byproducts have been expressed by many consumers over the years, but the guarantee of safety is very important. Hypochlorite can also be generated on site from salt solutions.

The reliability of this disinfection process is attested to by the dramatic decrease in water-borne disease in all areas where chlorination is reliably practiced.

The effectiveness of chlorination is affected by several variables--pH, chlorine dosage, temperature, contact time, ammonia concentration, and turbidity. The pH effect is well known; the more effective hypochlorous is the predominant chlorine species less than pH 7.5, and the much less effective hypochlorite ion is predominant greater than this pH. Temperature affects the disinfection reaction as any other in that higher temperature increases the speed of the reaction. Bacteria kills of 99.99+ percent can be achieved for secondary effluents at a chlorine dose as low as 5 mg/l with a 30-minute contact time. Shorter contact times require higher dosages. Viruses are more resistant so that closer control of operational conditions must be observed. Among those required are:

1. Turbidity less than 1.0 NTU, preferably less than 0.1 NTU;
2. pH close to 7.5;
3. 30 minutes contact time;
4. Good distribution of the chlorine throughout the water; and
5. Chlorine residual of at least 0.5 mg/l.

Under these conditions, it is possible to get virus inactivation efficiencies greater than 99.99+ percent (Parkhurst et al., 1977)[1].

Ozone has been used for many years as the primary disinfectant for drinking water in Europe. As stated previously, it is an effective disinfectant and is a stronger oxidant than chlorine. Its acceptance in the United States has been limited by its property of rapid decomposition, which leaves no residual in the distribution system. Several utilities, though, have followed ozonation with a low dose of chlorine, which provides the necessary residual for monitoring and assurance of system integrity. Ozone is generated on site from air or oxygen using a high-voltage, electrical discharge.

The operation of the ozonation process is simply the maintenance of a constant source of influent gas and electrical equipment. Feed rates are more difficult to vary than chlorine feed rates, but the dilute gases used are less dangerous than chlorine.

Ozone is essentially 100-percent effective in eliminating pathogens. It is more effective than chlorine for inactivating viruses and has the additional advantage of its strong oxidizing capacity, frequently eliminating tastes, odors, and color from water.

As with chlorine, the presence of suspended solids can interfere with ozone disinfection by providing a haven for pathogens.

Waste Disposal

The wastewater renovation facility for Jeddah will have two main process by-products to be disposed: chemical sludges, either alum or lime, and a concentrated brine solution, which will be the reverse osmosis reject stream. Mecca would not have the brine to dispose. The chemical sludges will be produced as a result of either alum coagulation or lime softening and will be precipitated in the upflow clarifier unit. Disposal of these sludges can be accomplished by gravity sludge thickening followed by mechanical dewatering devices or by construction of evaporation lagoons or sand drying beds.

Due to the scarcity of land available for either evaporation lagoons or sand drying beds in Mecca and Jeddah, an alternative means of disposal involves the use of lime recalcination. Sludge volume is greatly reduced by burning the lime sludge in a furnace such as a multiple hearth, driving off water and CO_2.

$$CaCO_3 \xrightarrow[\overset{\uparrow}{heat}]{} CaO + CO_2 \uparrow$$

The resultant product of calcium oxide (CaO) can be slaked and reused. A small sludge volume will be produced as excess lime sludge will be generated. In addition, a portion of the recalcined lime must be wasted to avoid the buildup of inert solids. The CO_2 in the off-gas can be used in the recarbonation process.

The second waste product to be disposed at Jeddah was the reject stream from the reverse osmosis units. Approximately 40 percent of the influent to these units will be wasted. This influent has been treated sufficiently so that the reject stream will be clear, colorless, and odorless. It will, however, contain the dissolved organic and inorganic materials which have been removed from the influent passed through the semi-permeable membrane. The liquid will be similar to sea water in nature but will have much less salinity. An inexpensive yet effective means of disposal would be to convey the stream to the Red Sea, either by an open ditch or a more costly closed pipe. Another option is evaporation in a lagoon, which can be lined to prevent infiltration of the saline water into the ground.

It should be emphasized that this waste stream has been sufficiently pretreated to be relatively free of harmful contaminants. It will be innocuous and not offensive in nature. However, the addition of a small amount of disinfectant may be prudent in order to ensure odor-free operation of the evaporation lagoons or to ensure that the discharge to the Red Sea is free of pathogens.

SELECTED OVERALL TREATMENT SYSTEMS

Processing of effluent from the waste treatment plants can be considered as essentially similar to treating a river water supply. Just as the raw water quality of a river varies from time to time because of rainfall and changes in climate and season of the year, wastewater quality will also vary with treatment plant effluent. It essentially contains small amounts of suspended solids and turbidity which can easily be removed by the standard water treatment processes of coagulation, sedimentation, and filtration. In the case of Jeddah, the wastewater also contains mineral salts which are more difficult to remove. Although on some occasions the wastewater plant effluent may appear to be sufficiently clear so as to need no additional clarification, the above standard water treatment processes remove colloidal constituents which are always present and serve to ensure that even if the influent feed is of varying clarity, the water renovation facility effluent will always be clear and sparkling.

The average influent water qualities for the water renovation facilty at Jeddah and Mecca are shown in Table 3. It is seen that organic constituents, such as suspended solids and COD, are greater than desirable for most water reuse purposes, and must be removed in the water renovation process. The mineral salts at Jeddah are also high and should be modified either by demineralization or by dilution with municipal water from the desalting facilities. For public health reasons, it is also necessary to disinfect the water to prevent any possibility of bacterial or viral disease transmission.

The unit processes discussed individually above were incorporated into candidate systems which would provide water renovation to produce clear water supplies, with particular attention to organic and inorganic contaminants as well as disinfection. Major consideration was given to developing systems which would have a high degree of reliability and longevity and would be simple to operate. The resulting systems consisting of a train of unit processes are considered to be the least treatment which can be applied to achieve the desired water quality for reuse.

A review of the water quality available for renovation showed that the major concerns for both cities were turbidity, suspended solids, trace organics, and microbiological contaminants. Jeddah, in addition, had an excessively high dissolved mineral content. Mecca had a high ammonia content.

Several potential combinations of unit processes were postulated for each city. The resultant finished water quality was estimated. For example, three of the processes for Jeddah were:

1. a. Coagulation/lime softening/sedimentation
   b. Recarbonation
   c. Filtration
   d. Reverse osmosis
   e. Chlorination
2. a. Alum coagulation/sedimentation
   b. Filtration
   c. Reverse osmosis
   d. Ozonation
3. a. Coagulation/lime softening/sedimentation
   b. Recarbonation
   c. Filtration
   d. Ozonation

The resultant water qualities are shown in Tables 11, 12, and 13 and Figure 11.

The process recommended after consideration of all factors was that listed above as Number 1. Each of the proposed processes would have to be preceded by a flow equalization basin to receive the wastewater treatment plant effluent, which has a large diurnal flow variation, prior to treatment for water renovation. In order to allow flexibility in operation and accommodate large variations in flow, the basin shouldr have a size of 43,500 m^3 to accommodate a feedwater supply. The basin can be an uncovered lagoon with impermeable bottom and sides, but it should be aerated sufficiently to maintain an oxygen residual at all times. The basin will then ensure a constant and equalized flow to the water renovation facility.

A schematic of this process is shown in Figure 12. This process stream would result in an effluent that would be clear, colorless, odorless, tasteless, and free of pathogenic organisms. It would be low enough in TDS to be suitable for any of the proposed water uses.

A similar screening process was utilized for Mecca with the favored process as follows:

1. Flow equalization,
2. Coagulation/lime softening/sedimentation,
3. Ozonation,
4. Recarbonation,
5. Filtration, and
6. Chlorination to produce chloramines.

An ozonation step was added after the lime softening step as a primary disinfectant.

The effect of each unit process in the stream is shown in Table 14, and a schematic of the process is shown in Figure 13.

Use of this series of unit processes would result in an effluent which would be clear, colorless, odorless, tasteless, and free of any pathogenic organisms. It would be sufficiently low in TDS to be suitable for many proposed renovated water uses, such as irrigation, fire fighting, and most industrial uses.

SYSTEM DESIGN

Jeddah

The entire system as designed for Jeddah consisted of the following units:

1. Flow equalization basin. Because of a large diurnal flow variation to the sewage treatment plant, this basin was designed to contain 43,500 m^3 of treated effluent. It is to be an uncovered lagoon with an impermeable bottom and sufficient aeration to assure an oxygen residual at all times. This unit guarantees a constant flow to the subsequent treatment units.

2. Coagulation, lime softening, and sedimentation are to be carried out in up-flow, solids contact units. Suspended solids, including the $CaCO_3$ precipitated in the softening process, will be removed by sedimentation. The TDS will be reduced from about 6,000 to 5,400, and the calcium ion will be reduced in order to minimize precipitation in the RO process. Lime dosage was estimated at 300 mg/l, as 90 percent CaO with a polymer feed of 1 mg/l.

3. Recarbonation basins will provide for retention of the softened water during exposure to CO_2 for pH reduction. The CO_2 will be obtained from the off-gases from the recalcining kiln. It was estimated that 20 to 30 mg/l of CO_2 would be required.

4. Recalcining. A kiln will be provided to convert the solid sludge from the softening basin to lime. The CO_2 from the off-gases will be used for recarbonation.

5. Filtration will be accomplished in gravity dual media filters to provide a clear, high quality water to the reverse osmosis units.

6. Reverse osmosis units will provide for demineralization from over 5,000 mg/l TDS to less than 600 mg/l. The unit is expected to produce about 60 percent product water and 40 percent reject. This, then, would be approximately 30,000 m^3 per day at design capacity. The RO-unit influent would be treated with 1 mg/l of sulfuric acid (H_2SO_4) and 1 mg/l of hexametaphosphate.

7. Chlorination would be the final process at the treatment plant to provide for destruction of all pathogens. The dosage required would be 10 to 20 mg/l.

8. Storage will be provided at an elevated position outside the city in order to provide adequate head for gravity flow with a minimum of 20 meters of head. The storage reservoir was designed to hold 50,000 m^3, sufficient for the recommended five flow requirements for a city of 1.2 million population. Rechlorination facilities will be provided at the reservoir site and a parallel, dual distribution system will be used to distribute the water to the developing areas of the city.

A preliminary estimate of the total cost of the treatment plant and reservoir was SR 150 M.

Mecca

The system as designed for Mecca was somewhat simpler because it was not necessary to provide for demineralization, although the higher ammonia content did necessitate a change in the residual disinfectant to chloramines. In essence, the major changes were as follows:

1. The elimination of the RO unit, since water with the predicted TDS can be used for most of the purposes originally envisioned.

2. The use of ozone, at up to 5 mg/l, as a primary disinfectant ahead of the recarbonation unit.

3. Chlorination to the monochloramine form as a residual disinfectant with the goal to produce approximately a 5-mg/l monochloramine residual.

The same flow equalization, softening, recarbonation, recalcination, and filtration processes would be included along with the same size storage reservoir. The overall capital costs were estimated to be SR 83 M.

SUMMARY

Water renovation facilities have been designed for the cities of Jeddah and Mecca in order to utilize the available wastewater as a source of secondary water system. It is required that the water be clear, colorless, odorless, and tasteless in order to be used by the public in any way.

The major problems to be solved were the high dissolved solids and pathogens at Jeddah and high ammonia and pathogens at Mecca.

The current wastewater treatment plants in both cities are designed to treat 50,000 m^3/day, which is only part of the total wastewater of either city, but is the maximum that is available from the existing sewerage.

The systems proposed will produce a water at Jeddah having less than 500 mg/l TDS (based on the average influent water quality at the time of the study). The Mecca plant will produce a water with TDS approximately equal to that of the influent, but still low enough to be used for most secondary water applications. Both plants will provide a water that is clear, colorless, odorless, and tasteless, and will distribute the water to the newly developed parts of the city as much less expensive alternatives to the current supplies.

REFERENCE

1. Parkhurst, J.D., et al. February 1977. "Pomona Virus Study, Final Report," California SWRCB and U.S. EPA.

Table 1. Drinking Water Quality Criteria (all units in mg/l except as noted)

Parameters	Drinking Water Maximum Contaminant Level (MCL)	
	World Health Organization	Environmental Protection Agency
Primary Regulations		
Arsenic	0.05	0.05
Barium	1.0	1
Cadmium	0.01	0.010
Chromium	0.05	0.05
Cyanide	0.05	—
Fluoride	0.7 to 1.7*	1.4 to 2.4*
Lead	0.1	0.05
Mercury	—	0.002
Nitrate	50 (as NO_3)	10 (as N)
Selenium	0.01	0.01
Silver	—	0.05
Radium, p Ci/l	3	5
Endrin	—	0.002
Lindane	—	0.004
Methoxychlor	—	0.1
Toxaphene	—	0.005
2,4-D	—	0.1
2,4,5-TP Silvex	—	0.01
Turbidity, TU	—	1†
Coliform Bacteria (colonies/100 ml)	1	1**
Secondary Regulations		
Chloride	200-600	250
Copper	0.05	1
Iron	0.1	0.3
Manganese	0.05	0.05
Sulphate	250	250
Zinc	5.0	5
Color, units	—	15
Foaming Agents (as MBAS)	—	0.5
Odor, TON	—	3
Other		
Trihalomethane	—	0.10

* Varies with average annual maximum daily air temperature.

† Monthly average.

** Monthly average, membrane filter technique.

Source: U.S. Environmental Protection Agency, 1976.
World Health Organization, 1971.

Table 2. Critical Design Parameters from Wastewater Effluent Data

Parameter	Jeddah	Mecca
Temperature (°C)	31.9	30.6
Percent Used Capacity	64	41
BOD (mg/l)	40	24
Cl^- (mg/l)	3,479 (very high)	388 (acceptable)
TDS (mg/l)	6,065 (very high)	1,739 (acceptable)
Total Hardness (mg/l)	1,726 (very high)	582 (high)
Noncarbonate Hardness (mg/l)	1,282 (very high)	174 (acceptable)

Source: Environmental Science and Engineering, Inc., 1980.

Table 3. Typical Domestic Wastewater Characterization--Average Concentrations*

Constituent/Plant	14-Plant Average†
BOD	181
COD	417
TSS	192
NH_3-N	20
NO_3-N	0.61
Org-N	13
Ortho-P	6.8
Total-P	9.4
Alkalinity	211
Oil and Grease	61
pH	7.2
Arsenic	0.007
Barium	0.235
Cadmium	0.008
Chromium	0.167
Copper	0.117
Fluoride	0.864
Iron	2.25
Lead	0.148
Manganese	0.117
Mercury	0.112
Selenium	0.006
Silver	0.022
Zinc	0.419
Endrin**	0.005
Lindane**	0.260
Methoxychlor**	0.102
Toxaphene**	0.001
2,4-D**	0.152
2,4,5-TP Silvex**	0.110
TOC	102
Hardness	362
Color P-C Units	67
Turbidity, FTU	2.16
Foaming Agents	1.07
TDS	2,577

* All values in mg/l except as noted.
† Average from 14 data sources.
** ppb.

Source: U.S. Department of the Interior, Water Reuse and Recycling, 1979.

Table 4. Expected Constituent Removal by Unit Processes

Constituent	Primary Treatment	Trickling Filters	Softening	Coag-Floc-Sed	Filtration	Selective Ion Exch.	Reverse Osmosis	Chlorination	Ozone
BOD	**	***	*	***	**	**	***		*
COD	**	***	*	***	**	**	***		***
TSS	***	***	***	***	***	***	***		***
NH_3-N	*		**	*	**	***	***		
Chloride					**		***		
Phosphorus	*			***	***		***		
Alkalinity			***	**	***				
Oil and Grease	***			**					
Total Coliform		*	***	***				***	***
TDS			**				***		
Arsenic	**			**	***				
Barium			**	**	*				
Cadmium	**	*	***	***	**				
Chromium	**	*	***	***	**				
Copper	**	***	***	***	*				
Fluoride			**	**					
Iron	**	**	***	***	***				
Lead	***	**	***	***	*				
Manganese	*	*	***	**	***		***		
Mercury	*	*	**	*	**				
Selenium	*			*	***				
Silver	***	**	***	***					
Zinc	**	*	***	***					
Color	*	*	**	***	**		***	**	***
Foaming Agents	**	***		**			***		*
Turbidity	**	**	***	***	***		***		
TOC	**	**	***	***	**	*	***		***

* 25-percent removal of influent concentration.
** 25- to 50-percent removal of influent concentration.
*** >50-percent removal of influent concentration.
Note: Blank denotes no data or inconclusive results.

Source: U.S. Department of the Interior, Water Reuse and Recycling, 1979.

Table 5. Wastewater Characteristics of Three San Francisco Area Wastewater Treatment Plants--Average Concentrations*

Constituent/Plant	A	B	C
BOD	216	297	144
COD	598	871	321
TSS	193	406	153
NH_3-N	13.8	15	18
NO_3-N	1.52	0.21	0.09
Org-N	7.0	15.3	14
Ortho-P	3.4	3.0	3.3
Total-P	7.2	9.6	7.8
Alkalinity	143	124	91
Oil and Grease	35	104	44
pH	7.0	7.2	
Arsenic	0.003	0.004	0.008
Barium	0.136	0.041	0.140
Cadmium	0.004	0.006	0.002
Chromium	0.560	0.213	0.029
Copper	0.156	0.217	0.067
Fluoride	1.36	0.90	0.6
Iron	3.54	2.78	1.24
Lead	0.206	0.203	0.100
Manganese	0.111	0.195	0.044
Mercury	0.004	0.003	0.003
Selenium	0.005	0.001	0.014
Silver	0.044	0.034	0.013
Zinc	0.641	1.195	0.193
Endrin†	—	0.007	0.003
Lindane†	0.021	0.7	0.06
Methoxychlor†	0.20	0.08	0.027
Toxaphene†	0.001	0.002	0.001
2,4-D†	0.017	0.4	0.04
2,4,5-TP Silvex†	0.120	0.14	0.07
TOC	100	171	73
Hardness	389	672	84
Color P-C Units	39	55	108
Turbidity, FTU	91	152	78
Foaming Agents	1.81	1.53	2.8
TDS	1,918	5,259	554

* All values in mg/l except as noted.

† ppb.

Source: U.S. Department of the Interior, Water Reuse and Recycling, 1979.

Table 6. Primary Treatment--Average Contaminant Removal (%)

Constituent/Plant	Data Source (percent)			Average** (percent)
	I*	A†	B†	
BOD	34-47	48	50	42
COD		36	38	38
TOC		30	36	34
TSS	53-64	46	54	53
NH_3-N		17	19	18
Phosphorus		27	26	27
Alkalinity		+	+	+
Oil and Grease	61	67	63	65
Color		18	12	15
Foaming Agents††		30	23	27
Turbidity		31	30	31
Arsenic		28	40	34
Cadmium	30	30	45	38
Chromium	32-36	†	44	44
Copper	36-40	40	58	49
Iron	57	43	42	43
Lead	54	51	53	52
Manganese	27	14	26	20
Mercury			11	11
Selenium		0	0	0
Silver	46	56	54	55
Zinc	36-50	38	34	36

* Typical removals from the literature.
† Source: CH2M Hill (1974).
** Average of four sites.
†† Surfactants.
Note: + = Increase.

Source: U.S. Department of the Interior, Water Reuse and Recycling, 1979.

Table 7. Trickling Filters--Average Contaminant Removal** (Values given in terms of percent removal)

Constituent	Data Source		Increase Over Primary Treatment
	*	Average†	
BOD	70-95	69	27
COD		58	20
TSS	69-92	63	10
Cadmium	5	0	
Chromium	19	0	
Copper	46	56	
Lead	36	44	
Manganese	16		
Mercury		0	
Silver	48		
Zinc	56		

* Typical removals from the literature.
† Average removal from four data sources.
**Based on raw water followed by primary treatment.

Source: U.S. Department of the Interior, Water Reuse and Recycling, 1979.

Table 8. Coagulation-Sedimentation with Alum--Average Contaminant Removal (%)

Constituent	Data Source *	 A†	 B†	Average
BOD		80	72	76
COD	85	71	67	69
TOC	83	54	67	51
TSS		81	85	83
Alkalinity		13	19	16
Oil and Grease		91	87	89
Color		84	59	72
Foaming Agents**		57	52	55
Turbidity		87	85	86
Arsenic		32	54	83
Cadmium		68	76	72
Chromium	23-99	81	90	86
Copper	89	82	90	86
Fluoride		46	42	44
Iron		84	81	83
Lead	92	88	92	90
Manganese		37	43	40
Mercury		29	19	24
Selenium		0	0	0
Silver		90	88	89
Zinc	35	82	77	80

* Typical removals in published literature.
† Primary treatment.
** Surfactants.

Source: U.S. Department of the Interior, Water Reuse and Recycling, 1979.

Table 9. Softening with Lime--Average Contaminant Removal (%)

Constituent	Data Source			Average†
	*	A†	B†	
BOD	80-81		45	53
COD	81	31	32	52
TOC	78	18	29	73
TSS	88-90	67	72	65
NH_3-N	30	--		22
Phosphorus	95-98	--		91
Alkalinity	**			**
Oil and Grease		34	45	40
Color		61	35	46
Surfactants††		24	53	39
Turbidity			56	67
Arsenic	30	0	0	6
Barium	37	--	--	61
Cadmium	95	0	0	30
Chromium	11-97	34	60	56
Copper	84-97	41	51	55
Fluoride	3	48	52	50
Iron	40	95	97	87
Lead	97	27	25	44
Manganese	87-96	92	91	93
Mercury		0	0	0
Selenium	16	0	0	0
Silver	92-97	24	39	49
Zinc	90-98	83	86	78

* Typical removals in published literature.
† Following iron coagulation-sedimentation.
** Varies with hardness removed.
†† Surfactants.

Sources: U.S. Department of the Interior, Water Reuse and Recycling, 1979.

Table 10. Reverse Osmosis--Typical Contaminant Removal

Constituent	Percent Removal Chemically Clarified Primary Effluent	Secondary Effluent	Tertiary Effluent
TDS	93	95	94
Sodium	92	94	93
Calcium	>99	>99	—
Magnesium	>99	>99	—
Ammonia-N	90	95	—
Chloride	90	95	91
Sulfate	>99	>99	99
Phosphate	>99	>99	—
COD	66	>96	89

Source: U.S. Department of the Interior, Water Reuse and Recycling, 1979.

Table 11. Effect of the Unit Processes in System Number 1 on the Listed Water Quality Parameters for Jeddah

Parameter	Concentration, mg/1						
	Raw	Trickling Filter	Lime Softening	Recarbonation	Filtration	Reverse Osmosis	Chlorination
TDS	6,399	6,065	5,417	5,417	5,417	325	325
TSS	374	51.6	18	18	1	0	0
TH	1,827	1,726	1,326	1,326	1,326	13	13
Alk	458	444	40	40	40	10	10
Cl	3,638	3,479	3,479	3,479	3,479	175	175
N	35.5	10*	7	7	7	0.4	0
BOD	155	40.4	19	19	19	2	1.5
COD	250	90.3	43	43	43	4	2

* Typical result to be expected with improved treatment.

Source: Environmental Science and Engineering, Inc., 1980.

Table 12. Effect of the Unit Processes in System Number 2 on the Listed Water Quality Parameters for Jeddah

Parameter	Concentration, mg/l Raw	Trickling Filter	Alum Coagulation	Filtration	Reverse Osmosis	Ozonation
TDS	6,399	6,065	6,065	6,065	364	364
TSS	374	51.6	8.8	1	0	0
TH	1,827	1,726	1,726	1,726	17	17
Alk	458	444	373	373	10	10
Cl	3,638	3,479	3,479	3,479	175	175
N	35.5	10*	10	10	0.5	0
BOD	155	40.4	10	10	1	0.7
COD	250	90.3	28	28	3	1.5

* Typical result to be expected with improved treatment.

Source: Environmental Science and Engineering, Inc., 1980.

Table 13. Effect of the Unit Processes in System Number 3 on the Listed Water Quality Parameters for Jeddah

Parameter	Concentration, mg/l					
	Raw	Trickling Filter	Lime Softening	Recarbonation	Filtration	Ozonation
TDS	6,399	6,065	5,417	5,417	5,417	5,417
TSS	374	51.6	18	18	1	1
TH	1,827	1,726	1,326	1,326	1,326	1,326
Alk	458	444	40	40	40	40
Cl	3,638	3,479	3,479	3,479	3,479	3,479
N	35.5	10*	7	7	7	0
BOD	155	40.4	19	19	19	14
COD	250	90.3	43	43	43	20

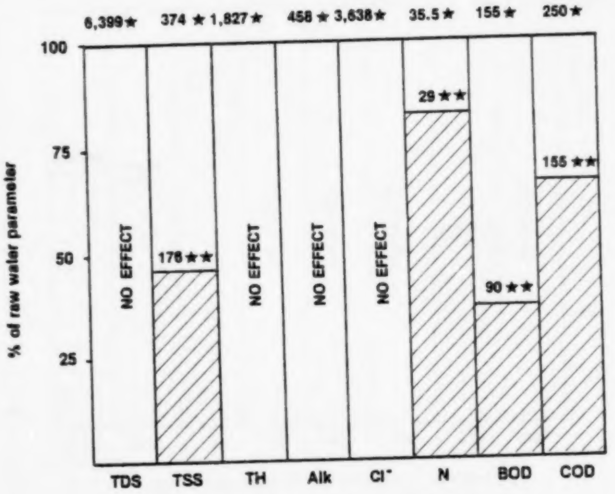
* Typical result to be expected with improved treatment.

Table 14. Effect of the Unit Processes in the Recommended System on the Listed Water Quality Parameters for the City of Mecca

Parameter	Concentration, mg/l					
	Raw	Trickling Filter	Lime Softening	Recarbonation	Filtration	Chlorination
TDS	1,678	1,678	1,143	1,143	1,143	1,143
TSS	364	30.2	10.6	10.6	<1	<1
TH	582	582	218	218	218	218
Alk	475	408	40	40	40	40
Cl	361	388	388	388	388	388
N	37	10*	7	7	7	0
BOD	160	24	11	11	11	7
COD	398	123	59	59	59	30

* Typical result to be expected with improved treatment.

Source: Environmental Science and Engineering, Inc., 1980.



SYMBOLS: TDS = Total dissolved solids , mg/l
TSS = Total suspended solids, mg/l
TH = Total hardness, as mg/l $CaCO_3$
Alk = Alkalinity, mg/l as $CaCO_3$
Cl^- = Chloride, mg/l
N = Ammonia nitrogen, as mg/l N
BOD = Biological oxygen demand
COD = Chemical oxygen demand

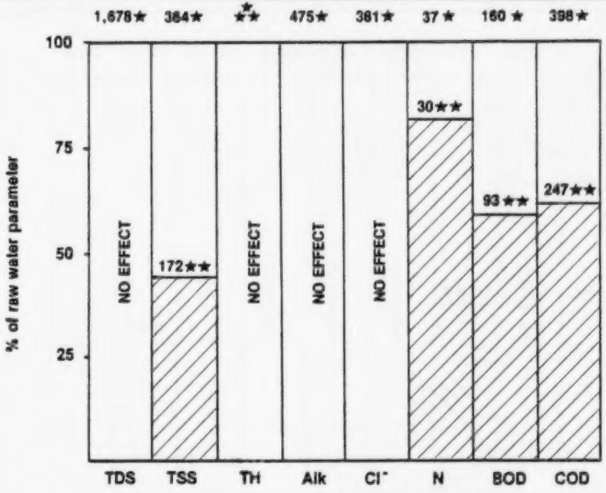
★ Average values for raw wastewater from Table 3

★ ★ Typical result to be expected

SOURCE: Environmental Science and Engineering, Inc., 1980

JEDDAH

Figure 1
EFFECT OF PRIMARY TREATMENT ON RAW WATER QUALITY PARAMETERS



SYMBOLS:
TDS = Total dissolved solids , mg/l
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Cl^- = Chloride, mg/l
N = Ammonia nitrogen, as mg/l N
BOD = Biological oxygen demand
COD = Chemical oxygen demand

★ Average values for raw wastewater from Table 3

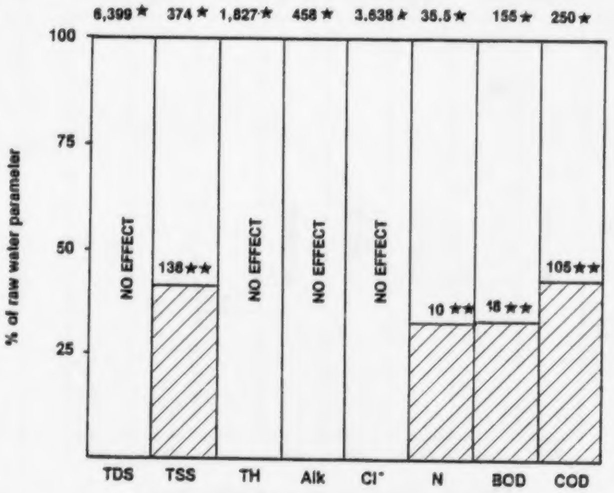
★★ Typical result to be expected

★★★ Unavailable from plant records

SOURCE: Environmental Science and Engineering, Inc., 1980

MECCA

Figure 2
EFFECT OF PRIMARY TREATMENT ON
RAW WATER QUALITY PARAMETERS



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Alk = Alkalinity, mg/l as $CaCO_3$
Cl^- = Chloride, mg/l
N = Ammonia nitrogen, as mg/l N
BOD = Biological oxygen demand
COD = Chemical oxygen demand

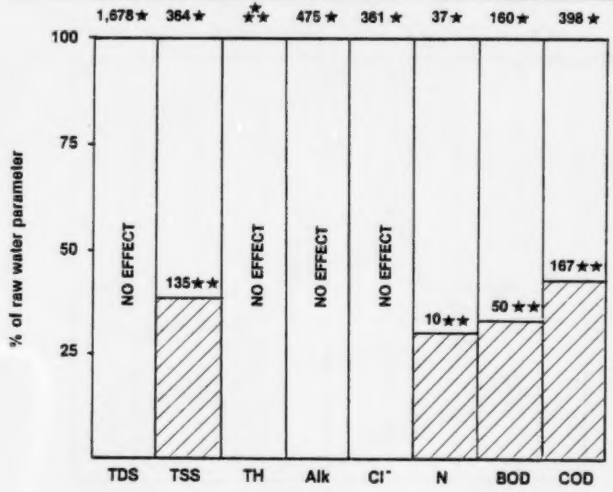
★ Average values for raw wastewater from Table 3

★★ Typical result to be expected

SOURCE: Environmental Science and Engineering, Inc., 1980

JEDDAH

Figure 3
EFFECT OF TRICKLING FILTERS ON RAW WATER QUALITY PARAMETERS



SYMBOLS:
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TSS = Total suspended solids, mg/l
TH = Total hardness, as mg/l $CaCO_3$
Alk = Alkalinity, mg/l as $CaCO_3$
Cl^- = Chloride, mg/l
N = Ammonia nitrogen, as mg/l N
BOD = Biological oxygen demand
COD = Chemical oxygen demand

★ Average values for raw wastewater from Table 3

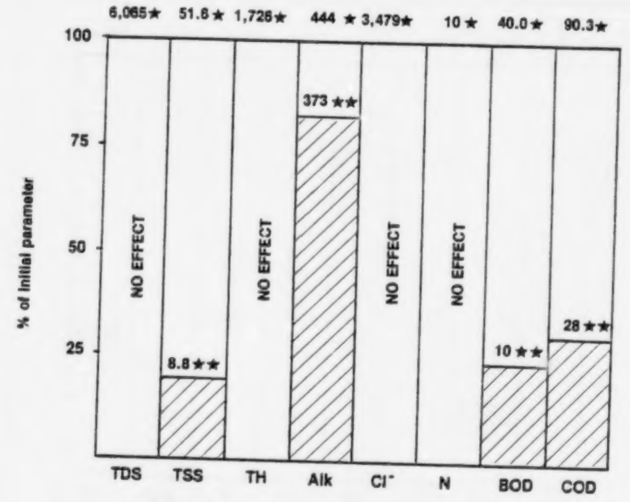
★★ Typical result to be expected

★★★ Unavailable from plant records

SOURCE: Environmental Science and Engineering, Inc., 1980

MECCA

Figure 4
EFFECT OF TRICKLING FILTERS ON
RAW WATER QUALITY PARAMETERS



SYMBOLS: TDS = Total dissolved solids, mg/l
TSS = Total suspended solids, mg/l
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Alk = Alkalinity, mg/l as $CaCO_3$
Cl^- = Chloride, mg/l
N = Ammonia nitrogen, as mg/l N
BOD = Biological oxygen demand
COD = Chemical oxygen demand

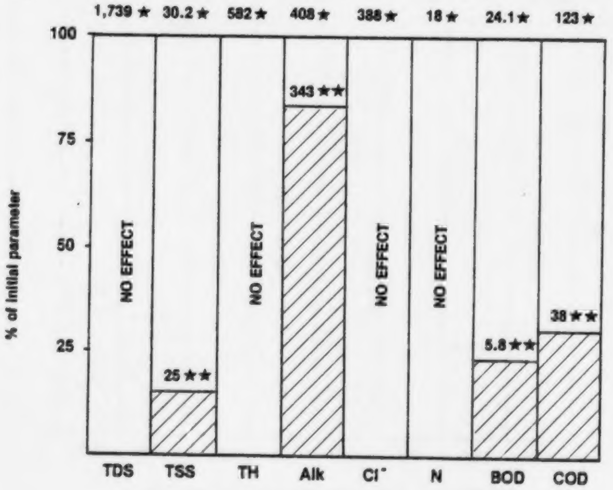
★ Average values for trickling filter effluent from Table 3

★★ Typical result to be expected

SOURCE: Environmental Science and Engineering, Inc., 1980

JEDDAH

Figure 5
EFFECT OF ALUM COAGULATION-SEDIMENTATION ON TRICKLING FILTER EFFLUENT QUALITY PARAMETERS



SYMBOLS: TDS = Total dissolved solids, mg/l
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Alk = Alkalinity, mg/l as $CaCO_3$
Cl^- = Chloride, mg/l
N = Ammonia nitrogen, as mg/l N
BOD = Biological oxygen demand
COD = Chemical oxygen demand

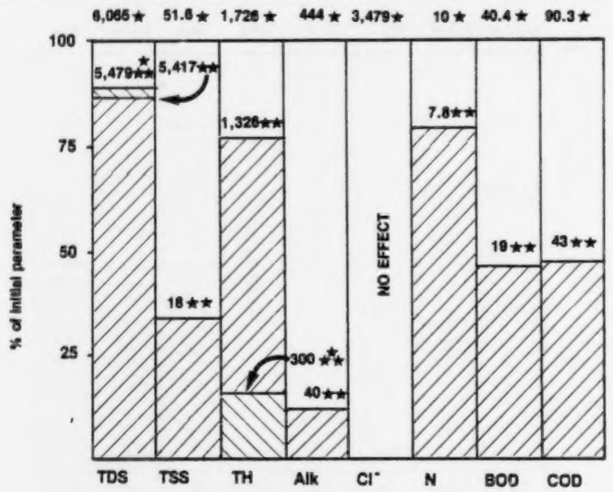
★ Average values for trickling filter effluent from Table 3

★ ★ Typical result to be expected

SOURCE: Environmental Science and Engineering, Inc., 1980

MECCA

Figure 6
EFFECT OF ALUM COAGULATION-SEDIMENTATION ON TRICKLING FILTER EFFLUENT QUALITY PARAMETERS



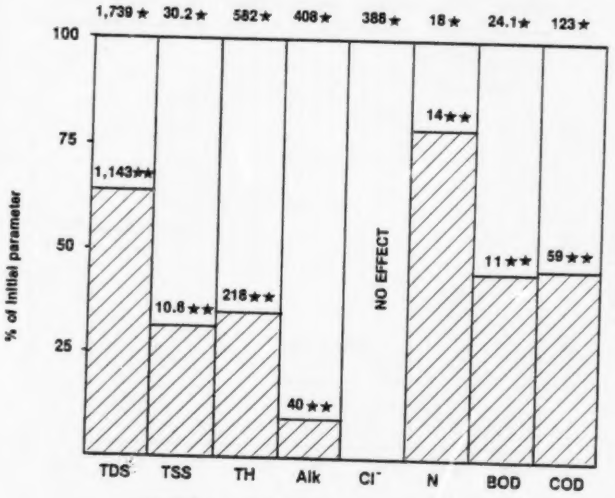
SYMBOLS:
TDS = Total dissolved solids , mg/l
TSS = Total suspended solids, mg/l
TH = Total hardness, as mg/l $CaCO_3$
Alk = Alkalinity, mg/l as $CaCO_3$
Cl^- = Chloride, mg/l
N = Ammonia nitrogen, as mg/l N
BOD = Biological oxygen demand
COD = Chemical oxygen demand

★ Average values for trickling filter effluent from Table 3
★★ Typical result to be expected from use of lime only
$\overset{★}{★★}$ Typical result to be expected if softening with lime and soda ash to final hardness of 300

SOURCE: Environmental Science and Engineering, Inc., 1980

JEDDAH

Figure 7
EFFECT OF LIME SOFTENING ON TRICKLING FILTER EFFLUENT QUALITY PARAMETERS



SYMBOLS:
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TSS = Total suspended solids, mg/l
TH = Total hardness, as mg/l $CaCO_3$
Alk = Alkalinity, mg/l as $CaCO_3$
Cl^- = Chloride, mg/l
N = Ammonia nitrogen, as mg/l N
BOD = Biological oxygen demand
COD = Chemical oxygen demand

★ Average values for trickling filter effluent from Table 3

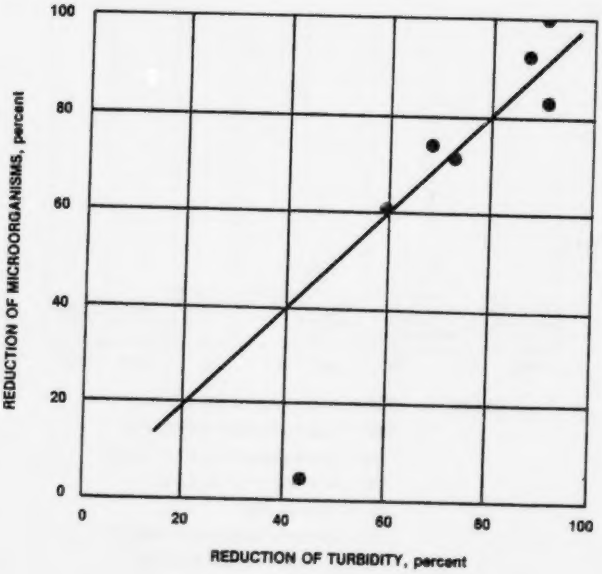
★★ Typical result to be expected

SOURCE: Environmental Science and Engineering, Inc., 1980

MECCA

Figure 8

EFFECT OF LIME SOFTENING ON TRICKLING FILTER EFFLUENT QUALITY PARAMETERS

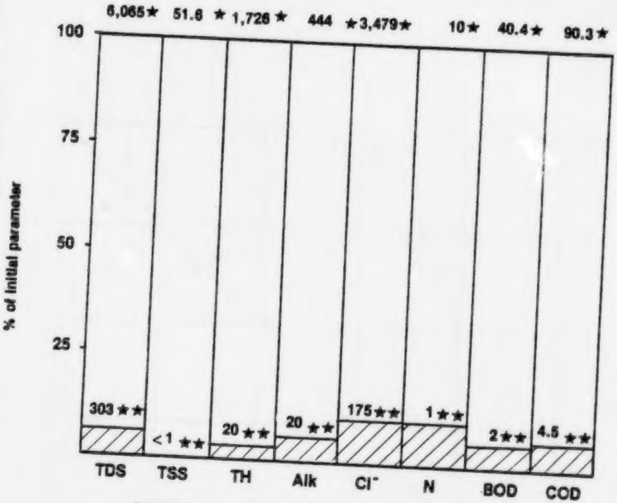


SOURCE: Environmental Science and Engineering, Inc., 1980

MECCA / JEDDAH

Figure 9

RELATIONSHIP BETWEEN MICROORGANISM REMOVAL AND TURBIDITY



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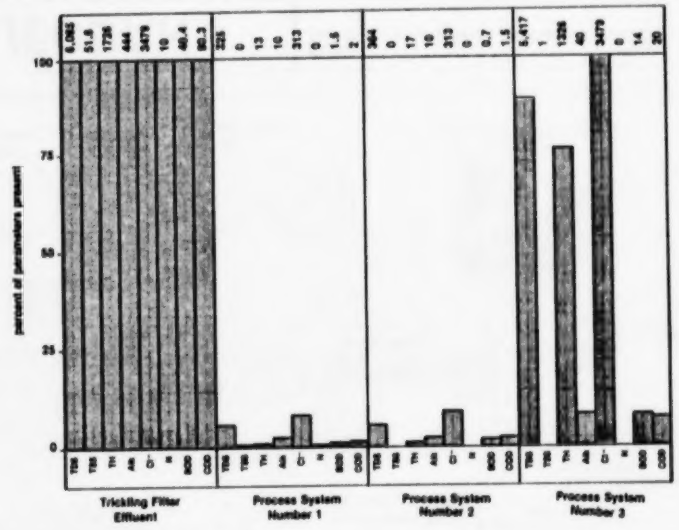
TSS = Total suspended solids, mg/l
TH = Total hardness, as mg/l $CaCO_3$
Alk = Alkalinity, mg/l as $CaCO_3$
Cl^- = Chloride, mg/l
N = Ammonia nitrogen, as mg/l N
BOD = Biological oxygen demand
COD = Chemical oxygen demand
★ Average values for trickling filter effluent from Table 3
★★ Typical result to be expected

SOURCE: Environmental Science and Engineering, Inc., 1980

JEDDAH

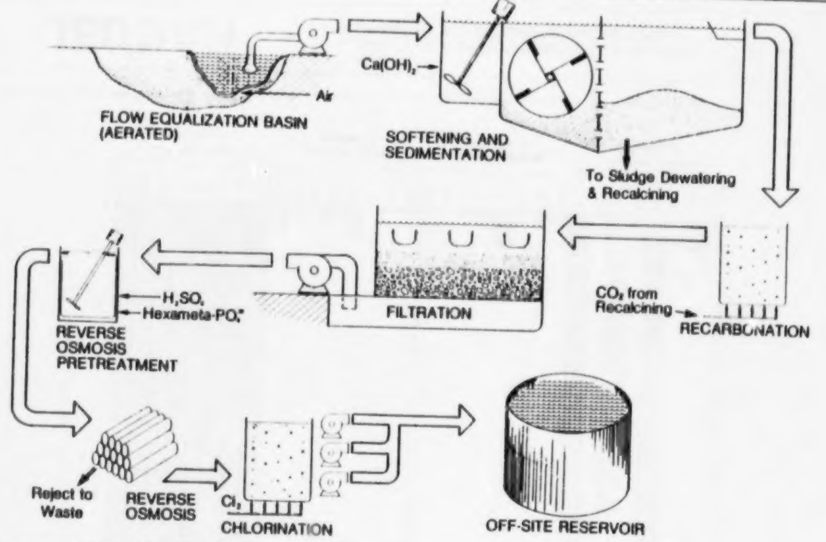
Figure 10
EFFECT OF REVERSE OSMOSIS ON TRICKLING FILTER OR COAGULATED AND SETTLED EFFLUENT QUALITY PARAMETERS



SOURCE: Environmental Science and Engineering, Inc., 1980

JEDDAH

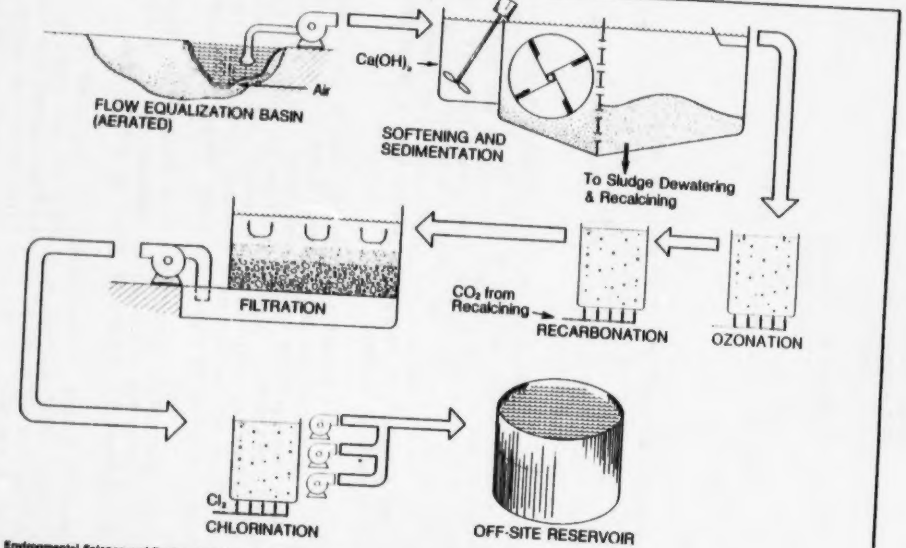
Figure 11
EFFECT OF CANDIDATE PROCESS SYSTEMS
ON LISTED WATER QUALITY PARAMETERS


FLOW EQUALIZATION BASIN (AERATED)
Air
$Ca(OH)_2$
SOFTENING AND SEDIMENTATION
To Sludge Dewatering & Recalcining
CO_2 from Recalcining
RECARBONATION
FILTRATION
H_2SO_4
Hexameta-PO_4*
REVERSE OSMOSIS PRETREATMENT
Reject to Waste
REVERSE OSMOSIS
Cl_2
CHLORINATION
OFF-SITE RESERVOIR

SOURCE: Environmental Science and Engineering, Inc.

JEDDAH

Figure 12
CITY OF JEDDAH—FINAL TREATMENT SCHEME


FLOW EQUALIZATION BASIN (AERATED)
Air
Ca(OH)$_2$
SOFTENING AND SEDIMENTATION
To Sludge Dewatering & Recalcining
FILTRATION
CO$_2$ from Recalcining
RECARBONATION
OZONATION
Cl$_2$
CHLORINATION
OFF-SITE RESERVOIR

SOURCE: Environmental Science and Engineering, Inc.

MECCA

Figure 13
CITY OF MECCA—FINAL TREATMENT SCHEME

PB82-223363

MUNICIPAL WATER REUSE IN AN ARCTIC COMMUNITY

BY
Juris Vitolins
Project Manager

BE&C Engineers, Inc.
625 Andover Park West
Tukwila, Washington 98188

Robert W. Claunch
#17 Village Auroa
4100 General DeGaule
New Orleans, Louisiana 70114

INTRODUCTION

North Slope Borough of the State of Alaska, is undertaking a program of providing improved housing for it's residents. This paper is about a municipal water recycling, collection, distribution and waste disposal system for a new housing complex (Browerville) at Barrow, Alaska.

Barrow is a North Slope community with an approximate population of 5,000 people, and is the northern-most point of Alaska. North Slope of Alaska is one of the most arid regions of the world in terms of total annual precipitation. Even though there is a great amount of ice and many streams and lakes, the water tends to stay in place due to the flat terrain and permafrost. The scarcity of fresh water and disposal of sewage has always been a great problem for communities such as Barrow.

In planning the 137 unit Browerville housing complex (apartments and homes), for approximately 500 persons, North Slope officials gave the water sewage problem to BE&C Engineers, Inc., a Boeing Engineering and Construction Company subsidiary. BE&C Engineers, Inc. were to perform the projects architectural and engineering work, as well as to act as Borough's Engineer during construction. Redux Corp. was selected to supply the water recycling system.

In 1979 at the Water Reuse Symposium I, the Browerville project was briefly discussed per the paper of reference (1). At that time, the project was in process of planning and design.

The water recycle system of the project was completed in September, 1980. After a three week check out and operator training period, the water recycle system was turned over to North Slope Borough to operate. Since that time the system has been operating very satisfactory, and the water recycle system has been producing good quality water.

REQUIREMENTS

Prior to approving this project, North Slope Borough and the State of Alaska officials required that the project satisfies economic, health, and safety requirements. Preliminary engineering studies had to be made, as noted per references (2) and (3) to convince North Slope Borough and State of Alaska to undertake this project.

In general the project had to comply with the following requirements:

1. Provide a central water/sewer distribution and collection system.
2. Eliminate the discharge of water/sewage on ground.
3. Provide a gray water recycling system.
4. Provide a system that is simple to operate and maintain.
5. No noxious odors were to be produced from any part of the system.
6. Provide a utilidor/utiliduct distribution system from the central building to the housing units.

Presently, the recycled water is being used for laundries and toilets. After the system has been producing good quality water for an unspecified time period, the State of Alaska health officials will review the Water Quality Reports and will determine whether to allow the use of the recycled water for showers.

SYSTEM DESCRIPTION

The housing complex which the system is to service consists of the following:

1. 9 twelve unit apartments
2. 1 eight unit apartment
3. 21 single family residences

A layout of the housing complex is provided per Figure 1.

A partial view of the apartments is provided per Figure 2. Per this view the twelve unit apartments, sump buildings and utilidors can be seen.

A central building floor plan is provided per Figure 3. The central building consists of the following:

1. Tanks
    2 - 9,000 gallon potable water tanks
    2 - 9,000 gallon waste water tanks

1 - 7,600 gallon gray water tank
2 - 9,000 gallon recycled water tanks

2. The Redux water recycling system
3. Glycol heating system boilers
4. Standby diesel generator
5. Fire protection system pumps and controls
6. System controls
7. Office, laboratory, toilet, etc.

The housing units are connected with the central building by a network of utility corridors called "utilidors", which are constructed from wood and insulation materials. Also used per the system are "utiliducts" which are insulated ducts that connect the residences with the sump buildings. Through the utilidors and utiliducts are routed, water and sewage, pipes, as well as electric power lines. The utilidors are heated with a glycol heating system, electric base heaters, and heat tracing tapes.

The gray and waste waters from the housing units are being discharged to the sump/pump tanks which are located in the sump buildings. After the discharges are collected to a pre-set level, they are pumped to the central building storage tanks.

A description of the Redux system is provided per The Water Recycling System section of this paper. A partial view of some of the components is shown per Figure 4.

SYSTEMS PROCESS

A process diagram of the system is provided per Figure 5. At present, potable and waste water tanks are being supplied and hauled away by trucks. In the future, as Barrow's water and sewage system is extended to the Browerville housing complex, the potable and waste water tanks will be hooked up with Barrows Water and Sewage Collection, and Distribution System and the truck operations will be eliminated.

DESIGN AND CONSTRUCTION

The design criteria for the system was as follows:

1. Population to be served

   Design - 500 persons
   Estimated - 410 persons

2. Water usage

   Design 50 gallons/day/person
   Estimated 24.5 gallons/day/person

3. Water usage (showers using potable water)

   Design potable water - 26 gallons/day/person
   Design recycled water - 24 gallons/day/person
   Estimated potable water - 21 gallons/day/person
   Estimated recycled water - 13.5 gallons/day/person

4. Water usage (showers using recycled water)

   Design potable water - 11 gallons/day/person
   Design recycled water - 39 gallons/day/person
   Estimated potable water - 9 gallons/day/person
   Estimated recycled water - 25.5 gallons/day/person

The system was designed for very adverse weather conditions, such as temperatures of -70°F and heavy snow drifts. Also, the system was designed to be as self sufficient as possible. As an example, in case of electric power failure the standby diesel powered generator would be activated, in case of glycol pump failure a standby pump would be activated, in case of low temperature in a zone back-up heating system would operate, etc.

The Redux system was designed to operate per manual or automatic mode.

An added benefit of the system is the availability of potable and recycled water for fire fighting. In Barrow 1,000 gallons fire trucks are used to haul water to fire sites. By the design of a "siamese" connection to large booster pumps the potable and recycled water tanks would be available by merely hooking up hoses to the tank connections.

Construction and material delivery for this project was very difficult. The Projects General Contractor was McCann Construction Company of Seattle, Washington. The Material Supply Contractor was H.W. Blackstock Company of Seattle, Washington. Nearly every phase of construction work was complicated by weather or material delivery problems. During the winter months, at times total darkness, low temperatures, and snow drifts were experienced. During summer months, the top layer of the permafrost thawed to create unstable mud up to 2 feet thick. In sub-zero temperatures, conventional oil and lubricants for machinery would turn to a gluey substance and engine heating equipment had to be installed. Materials had to be delivered by barges during a brief period during the summer months when the Arctic Ocean ice cleared. Materials at other times had to be delivered by aircraft.

North Slope Borough requested that native personnel be employed to perform much of the labor, and some of the skilled craft work. The construction contractors had to train these workers.

In spite of all the adverse factors that were encountered, the quality of construction was excellent and the system was put in operation with only minor Design/Construction related problems.

WATER RECYCLING SYSTEM

The water recycling system is a physical chemical air flotation type. Two additives are used; surfoc a patented chemical for enhancing the emulsion breaking characteristics of the other which is Aluminum Sulfate. Surfloc is added first, airation is accomplished next in an air disolving tube and aluminum sulfate addition is last.

A pH of 4.8 to 5.2 is maintained by a proportional controlled pump, and in line blending.

The dissolved air flotation cell, which was developed by Krofta Engineering Company, is used for separation of the dirty water from the clean water and floating solids. At pH 5, many of the metal ions are insoluble and therefore are removed as solids.

The recycled water is transfered into either of two 9,000 gallon tanks. The tanks are independent of each other so that as one tank is being filled the other tank suppies water to the residences. This allows a further cleaning of water which is constantly being circulated through two single media swimming pool filters. This circulation loop is monitored for pH and free chlorine residual. Since the water is processed at pH 5 a small amount of sodium hydroxide is added to increase the pH to approximately 7.2. Calcium hypochlorite is used as a chlorine source because of its ease of handling. Calcium chloride is constantly being fed as demanded by the controller. By the time a clean water tank is ready for use there has been a continual filtration and maintenance of free chlorine for over 24 hours.

The floc containing most of the suspended solids is transferred to the waste water holding tanks in which sewage is collected and stored to be hauled away by truck. Sludge dewatering is therefore not required.

The gray water is collected in an 7,600 gallon tank and held until one of the 9,000 gallon recycled tanks is empty. When the gray water tank is full, an automatic diverter valve sends the surplus water to the waste water holding tanks.

All system functions are redundant, which enables the operator to bypass a pump or valve in case of its failure. Should the process pump fail, the operator can change to the alternate pump merely by throwing a switch. The operator then has time to investigate the problem and replace the failed component with a spare without having to shut down the system.

SYSTEM OPERATION

The system was designed to process gray water at 75 gallons per minute. However, since the actual useage is much less, the system is operated at 50 gallons per minute. The system is actually operated about 3 hours per day. The operators are available around the clock, since they also have to perform maintenance functions on the total system.

The chemical usage has been less than the original amounts estimated because there is no requirement for adjusting the pH prior to treatment, and the recycled water is presently not being used for showers.

The sand filters have to be cleaned monthly because of "mud balling" but since this was anticipated, ease of cleaning was one of the major design considerations in selecting the filters. With an alum process, the carry over particulates are sticky and make filter backwashing difficult. A multimedia filter is almost impossible to maintain in this type of system, and the ability to remove the media and mud balls is of prime importance.

The operators were trained during a 3-week period, and for several months thereafter there was excellent technical support from the installation contractors in support of systems maintenance.

The water recycling system has been providing approximately 50% of the water needs of the residences. The recycled water is being used for toilets and laundries. For drinking and bathing, potable water is hauled to the central building from Barrow's water treatment plant.

The systems potable water and waste disposal combined costs is about 12 cents per gallon. The chemical costs are averaging about $1.41 per 1,000 gallons and the recycled water usage is averaging about 86,000 gallons per month.

WATER QUALITY

The water quality standards that are being monitored are as follows:

	Specification
Oil and grease	20 mg/l
Suspended solids	40 mg/l
Surfactants	20 mg/l
Hardness	100 mg/l
Total dissolved solids	3000 mg/l
pH	6.5 - 7.5
Turbidity	10 NTU
BOD	40
Total coliform	0

Although these standards are not for potable water, the useage for the water does not demand this. It is believed that intermittant internal consumption of this water is not harmful. However, the LD 50 oral toxicity test should be conducted to verify this conclusion. The only reason for concern is that small children might drink the bath water.

It should be remembered, that in most parts of the world, outside United States, water does not meet U.S. public health drinking water standards. The aesthetics of the recycled water are as good as the potable water that is available in Barrow. The importance of this is that the economics of water reuse are of great importance and conservation of energy and other natural resources is not served by excessively stringent regulations.

Included is a letter to North Slope Borough from the Water Testing Laboratory summarizing the water quality for the first 17 samples of the recycled water. (Appendix A)

CONCLUSIONS

We believe that the decision to recycle water in the Browerville subdivision is correct. The useage of water from the limited supply source has been reduced, and the sanitary conditions of the community have been improved.

This concept which has reduced potable water consumption by 50% will be improved even further when the water is being used for showers. This project can serve as a pilot for communities in other water scarce areas of the world.

The systems water quality could be further improved if necessary by other means. The most attractive being through the use of membranes. The water currently being produced through the Redux system should be in excellent condition for reverse osmosis treatment and will require much less energy than direct conversion from gray water.

In communities in which water is scarce, and which do not have waste water treatment plants, and/or laws do not allow for direct disposal on the ground, the water recycle approach should be considered.

ACKNOWLDEGEMENTS

1. North Slope Borough for requesting and partial funding of this project.

2. Alaska Department of Environmental Conservation for partial funding of this project.

3. To all the people that worked on this Project (Engineers, Contractors, Vendors, Clerical support, etc).

REFERENCES

1. Claunch, R.S., "Redux Water Recycling System" Water Reuse Symposium I, 1979

2. Water Distribution Sewage Collection and Partial Water Reuse Systems. BE&C Engineers, Inc., report for North Slope Borough, October 31, 1978

3. Water Recycling System Versus Water Treatment System. BE&C Engineers, Inc., report for North Slope Borough, May, 1979

Layout of Facilities

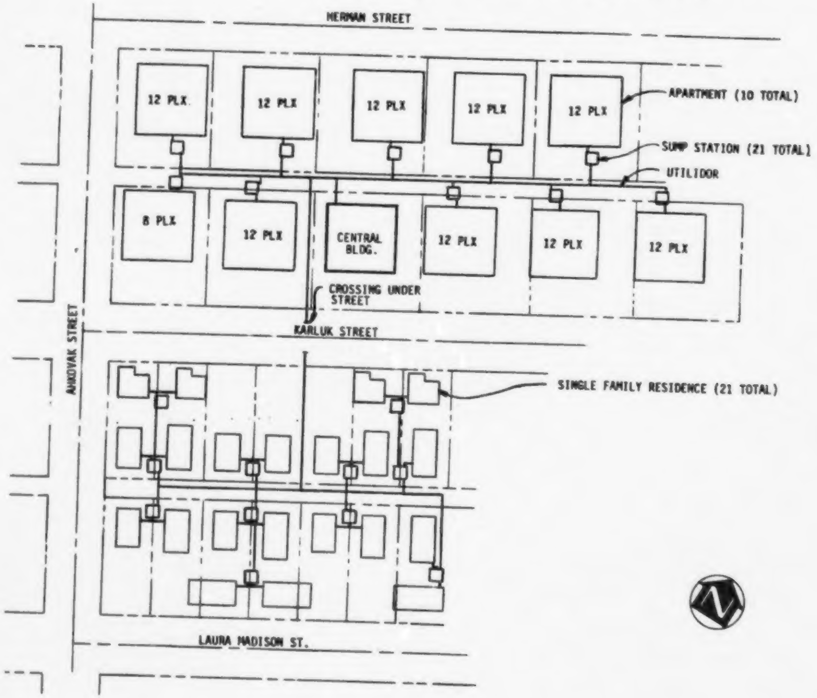

HERMAN STREET
12 PLX.
12 PLX
12 PLX
12 PLX
12 PLX
APARTMENT (10 TOTAL)
SUMP STATION (21 TOTAL)
UTILIDOR
8 PLX
12 PLX
CENTRAL BLDG.
12 PLX
12 PLX
12 PLX
CROSSING UNDER STREET
KARLUK STREET
AHKOVAK STREET
SINGLE FAMILY RESIDENCE (21 TOTAL)
LAURA MADISON ST.

Figure 1

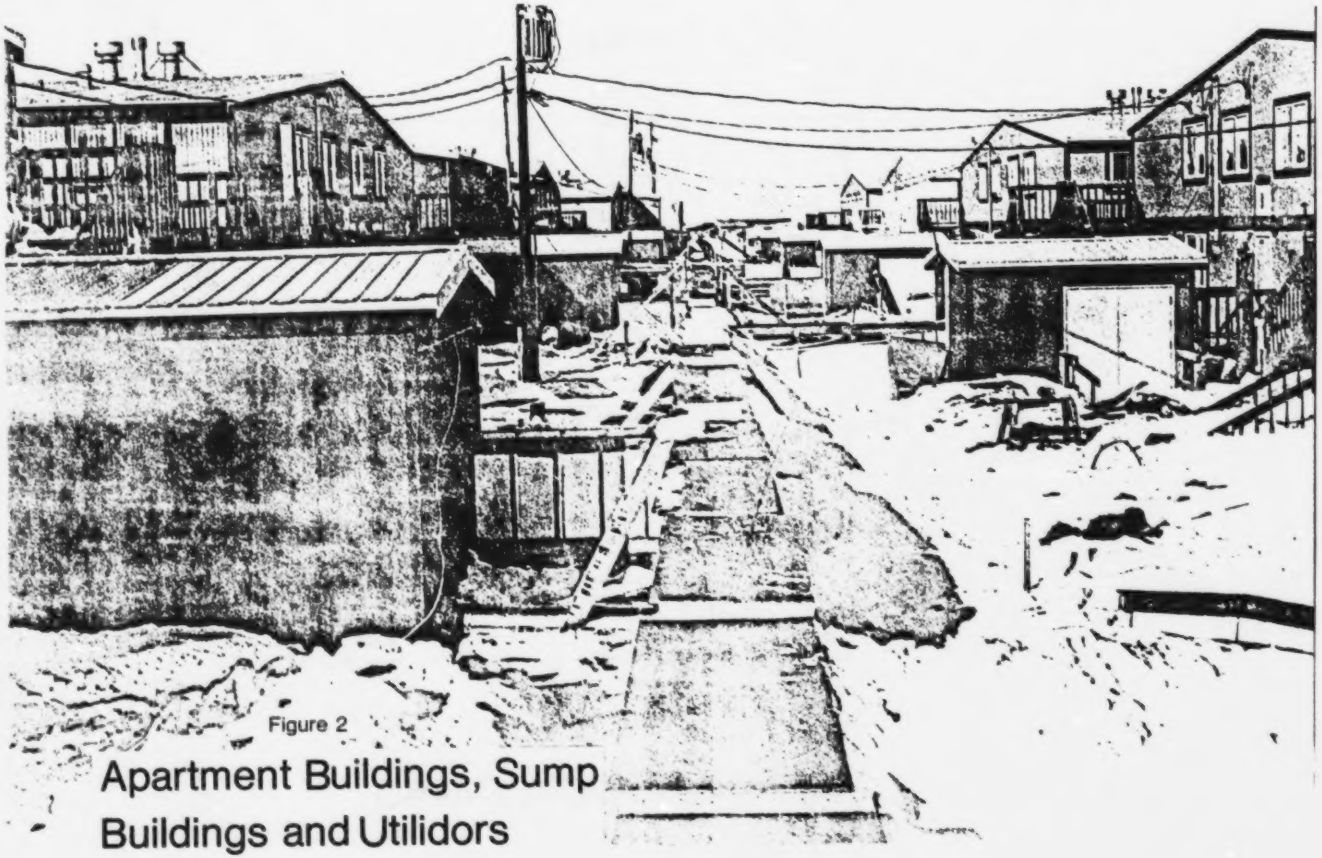


Figure 2

Apartment Buildings, Sump Buildings and Utilidors

Central building floor plan

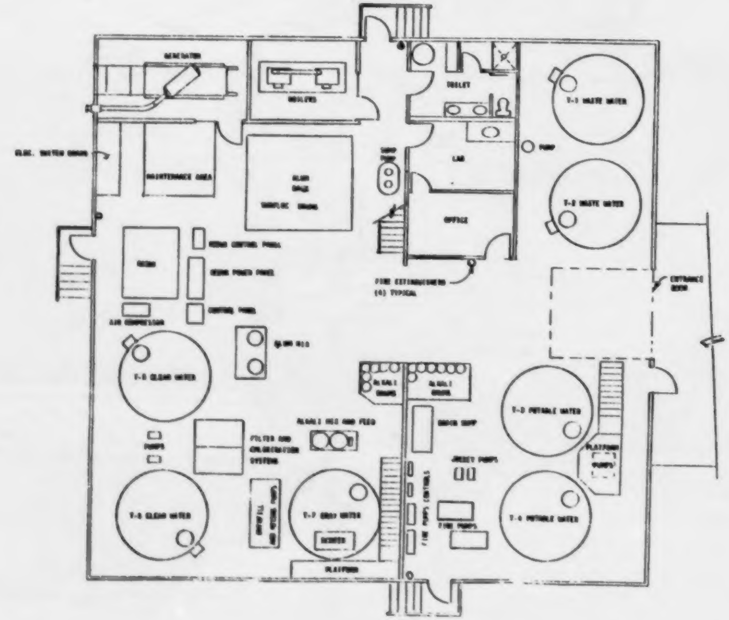

GENERATOR
BOILERS
MAINTENANCE AREA
TOILET
LAB
OFFICE
PUMP
T-1 WASTE WATER
T-2 WASTE WATER
FIRE EXTINGUISHERS
(4) TYPICAL
ENTRANCE
BERM
AIR COMPRESSOR
CONTROL PANEL
T-5 CLEAN WATER
T-6 CLEAN WATER
PUMPS
FILTER AND
CHLORINATION
SYSTEM
ALKALI MIX AND FEED
ALKALI
DRUMS
T-7 GRAY WATER
PLATFORM
JOCKEY PUMPS
FIRE PUMPS
FIRE PUMP CONTROLS
T-3 POTABLE WATER
T-4 POTABLE WATER
PUMPS

Figure 3

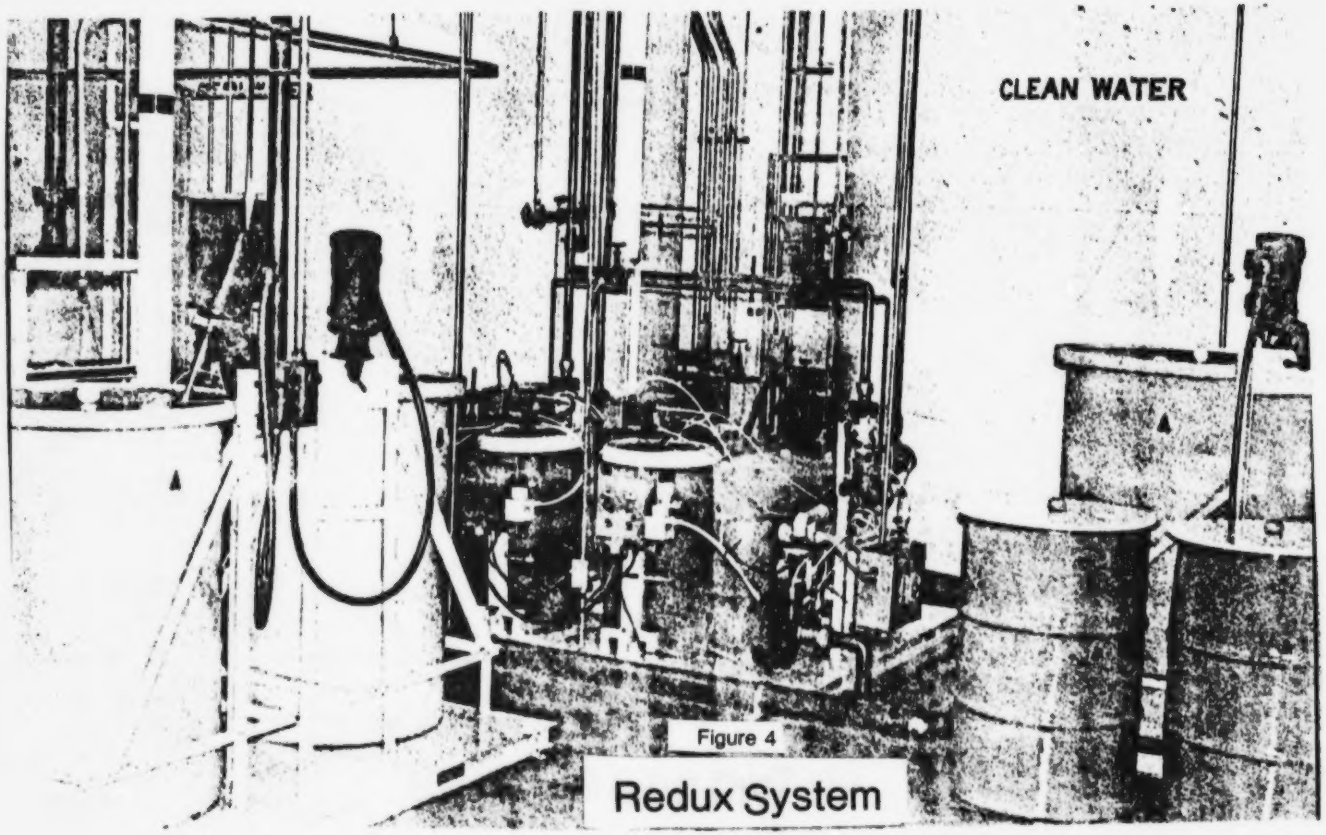

CLEAN WATER

Figure 4

Redux System

Schematic Flow Diagram

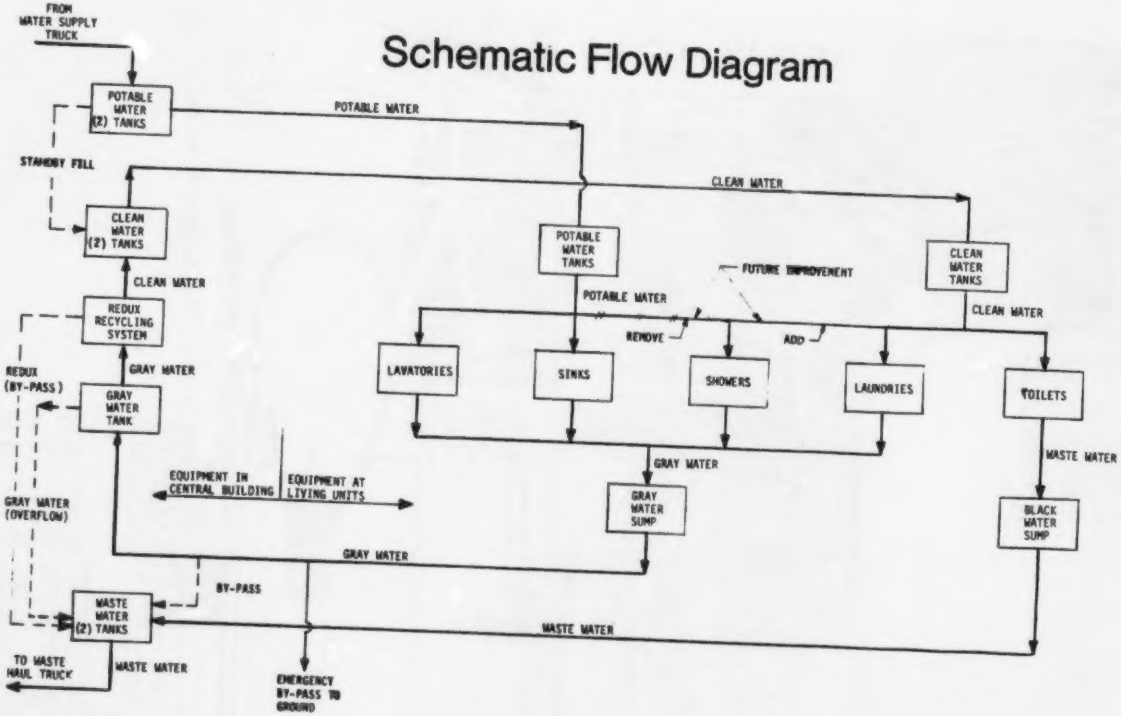

FROM WATER SUPPLY TRUCK
POTABLE WATER (2) TANKS
POTABLE WATER
STANDBY FILL
CLEAN WATER (2) TANKS
CLEAN WATER
POTABLE WATER TANKS
CLEAN WATER TANKS
FUTURE IMPROVEMENT
POTABLE WATER
CLEAN WATER
REMOVE
ADD
REDUX RECYCLING SYSTEM
GRAY WATER
LAVATORIES
SINKS
SHOWERS
LAUNDRIES
TOILETS
REDUX (BY-PASS)
GRAY WATER TANK
GRAY WATER
WASTE WATER
EQUIPMENT IN CENTRAL BUILDING
EQUIPMENT AT LIVING UNITS
GRAY WATER SUMP
BLACK WATER SUMP
GRAY WATER (OVERFLOW)
GRAY WATER
BY-PASS
WASTE WATER (2) TANKS
WASTE WATER
TO WASTE HAUL TRUCK
WASTE WATER
EMERGENCY BY-PASS TO GROUND

Figure 5

APPENDIX A

NORTHERN TESTING LABORATORIES, INC.
600 UNIVERSITY PLAZA WEST, SUITE A
FAIRBANKS, ALASKA 99701
907-479-3115

February 24, 1981

North Slope Borough
Utility Department
P. O. Box 69
Barrow, Alaska 99723

Attention: Jack Mask

RE: REDUX Water Recycling Plant Testing Program Progress Report

Dear Jack:

As per your request I have summarized the analytical data obtained from the first 17 samples from the Redux recycling plant operation. The enclosed data table outlines the ranges, average values, and % compliance with the engineer's performance specifications. Values for other significant parameters are summarized as well.

Overall, the Redux product water quality has been good. The system removes oil & grease, soaps (surfactants), and suspended solids very effectively. Some trouble was noted with pH control, particularly during the first few months, with improved performance lately.

Turbidity removal has been erratic, with nearly ¼ of the values in excess of the 10 NTU specification. The turbidity level appears to correspond to the color value in the clean water, indicating some inconsistency in the alum reation. The system is still undergoing a fine tuning process, which, in the past several months has resulted in very good color and turbidity removal.

The analysis for BOD indicates a steady increase in the accumulation of organic matter in the water. This problem could become serious if the total organic substrate begins to support in-line bacteria growth. A more aerobic grey water storage may help to reduce the BOD level.

Bacteria removals are better recently, although many of the early samples which did show contamination plated out as fecal coliform organisms. Apparently this problem has diminished with the last 6 samples showing only one positive for total coliform.

The hardness level has exceeded the performance specifications 41% of the time. This should not be viewed as a serious problem, but more that of an aesthetic one in terms of soap consumption and scaling.

In summary, the plant performance has been good. Some minor process chemical adjustments and improvements in the grey water quality have shown benefits in better product water. The organic substrate (BOD) problem still requires some attention.

Please call if you have any questions regarding this analysis.

Very truly yours

NORTHERN TESTING LABORATORIES, INC.

Michael R. Pollen

Michael R. Pollen
President

MRP/deb

NORTH SLOPE BOROUGH BROWERVILLE ADDITION REDUX WATER RECYCLING PLANT
TEST DATA FROM SEPT. 19, 1980 - FEB. 11, 1981

PARAMETER	UNITS	GREY WATER		CLEAN WATER		CLEAN WATER SPECIFICATIONS[1]	% COMPLIANCE WITH CLEAN WATER SPECIFICATIONS
		RANGE	AVERAGE	RANGE	AVERAGE		
Oil & Grease	mg/l	0.9-69	16.2	<0.1-12.7	3.1	20	100
Suspended Solids	mg/l	88-404	235	4.0-37	12.7	40	100
Surfactants	mg/l	0.5-17.8	8.8	0.63-6.80	3.8	20	100
Hardness	mg/l as $CaCO_3$	68.7-128	83.9	78.9-151	102.8	100	59
Total Dissolved Solids	mg/l	998-1410	1170	1100-1500	1300	3000	100
pH	pH units	6.1-7.7	-[2]	6.4-12.8	-[2]	6.5-7.5(range)	41
Turbidity	NTU	75 -240	140	0.8-19	6.3	10	76
20°c BOD_5	mg/l	37-250	122	<1-36	15.5	-	-
Total Coliform Bacteria	$\frac{\text{colonies}}{\text{100 ml}}$	0-TNTC	-[2]	0-TNTC	-[2]	-	Note: 50% of clean water samples were positive for coliform bacteria.
Color	color units	50-2500	725	<5-60	25	-	-

[1] Clean Water Specifications are "not to exceed" values unless stated otherwise. Specifications from BEC/REDUX performance standards

[2] Average not significant.

PB82-223371

A STUDY OF WASTEWATER REUSE IN THE BAHAMAS

John L. Roberts
Project Office Manager
Camp Dresser & McKee Inc.
3725 National Drive - Suite 220
Post Office Box 31585
Raleigh, North Carolina 27622

E. Lawrence Adams, Jr.
Associate
Camp Dresser & McKee Inc.
2001 Northwest 62nd Street
Post Office Box 9626
Fort Lauderdale, Florida 33310

INTRODUCTION

The economic foundation of The Bahamas is its tourist industry. Limited groundwater resources are being taxed by the increasing tourism and expanding native population of The Bahamas' most populated island, New Providence on which is located the resort city of Nassau. Water is currently barged 38 miles from Andros Island to supplement the New Providence Island supply. This costly source of supply is largely responsible for the existing rate of approximately $10 per 1,000 gallons for potable water from the New Providence Island water system. Given the high cost of potable water and its limited availability on New Providence Island, wastewater reuse deserves a high priority from an economic and water resources viewpoint; especially at tourist resorts where the average per capita consumption is roughly five times that of the domestic consumption.

A new luxury hotel and casino complex is planned for the Cable Beach area of New Providence Island. A feasibility study was conducted to develop a comprehensive plan for the design and construction of a system to adequately and reliably collect, treat, and reuse/dispose of wastewater generated from the Cable Beach study area. The oxidation ditch was selected as the primary treatment process prior to wastewater reuse for landscape irrigation and for toilet flushing by means of dual plumbing systems.

SELECTION OF SECONDARY TREATMENT PROCESS

One of the primary goals of the Cable Beach study was to select a treatment process which would provide a level of effluent quality that will allow various reuse applications. The wastewater generated from the hotel will be largely domestic in nature, with no industrial contribution. Of the many treatment processes available, the three selected for a detailed evaluation were oxidation ditches, rotating biological contactors, and extended aeration using a prefabricated unit.

For several important reasons the oxidation ditch was adopted as the recommended process. The oxidation ditch produces a high quality effluent, is a very reliable unit process, and is relatively simple to operate. These considerations are important given the subsequent use of the effluent, the limited operation staffing expected and the level of experience of available operating personnel. Furthermore, the process does not require sludge treatment, which eliminates the attendant potential for odor problems. It was considered mandatory for the study area that the selected process not create a nuisance. Additional deciding factors were the ability of the oxidation ditch to resist shock loads and the ability to construct the oxidation ditch with a large portion of local labor and construction materials.

WASTEWATER REUSE INVESTIGATIONS

The study included a thorough investigation of the potential uses of treated wastewater effluent most beneficial to the study area. Regulatory standards were reviewed and a detailed investigation of site conditions was undertaken to insure that each potential reuse and the mode of application would be done in a manner causing no nuisance, protecting public health, and creating no adverse environmental impacts. The most beneficial methods of treated wastewater reuse in the study area were found to be landscape irrigation and toilet flushing.

The standards for wastewater treatment are established and enforced by the Bahamas Department of Environmental Health. The Department presently has no rigid standards required for the reuse of treated effluent and evaluates each effluent reuse application separately. However, wastewater intended for reuse as envisioned in this project generally receives as a minimum secondary treatment followed by disinfection.

Reuse for Irrigation

The sites considered for treated wastewater effluent irrigation consist of approximately one-half of the 80-acre Cable Beach project site, an 80-acre portion of an existing golf course, and a small area of lawns and gardens around hotels and the casino.

Quality requirements for irrigation depend primarily upon the soil conditions, the plants and trees grown, and the exposure of people to direct contact with sprays or to indirect contact with irrigated surfaces. In view of the uses of the land to be irrigated, the most stringent requirements are imposed by possible exposure to people. These considerations as well as climate, topography, and groundwater use also determine irrigation rates, methods, and monitoring requirements.

Since the Bahamas Department of Environmental Health has no specific standards for landscape irrigation, considerable effort was spent on deciding the level of treatment required. This consisted of a literature search and review of criteria established by several states in the United States.

There is a lack of evidence relating nonpotable effluent reuse to documented cases of microbiological infection. However, the known presence of a large variety of disease-causing microorganisms in untreated domestic wastewaters is of concern. The aerosol or other means of pathogen transmission from inadequately treated sprayed effluent must be considered a potential danger. Therefore, the necessary precaution must be taken to prevent the transmission of pathogens in an effluent reuse system.

Disinfection of wastewater, as commonly practiced today, is highly effective in achieving large reductions of bacterial pathogens but not as effective against enteric viruses. Disinfection is accomplished by chlorinating the treated effluent before reuse. The primary objective of wastewater chlorination prior to its reuse is the removal of pathogenic organisms. Chlorine added to secondary treated wastewater reacts to oxidized chemical impurities prior to accomplishing any significant disinfection.

Chlorine dosage for virus disinfection (e.g., "breakpoint" chlorination) is not absolutely necessary for all effluent reuse applications. Some experts are of the opinion that nonpotable reuse applications similar to those considered in the study area should only be required to meet a very low coliform bacteria criteria. This could be achieved with lower chlorine dosages than the one required for breakpoint chlorination.

The state standards reviewed varied to some extent concerning treatment level required for reuse purposes. These treatment levels generally range from secondary treatment to a secondary treated effluent that has been coagulated by chemical addition and then filtered. The primary argument supporting filtration is additional reduction of bacterial pathogens and enteric viruses. Experts are in disagreement as to the amount of concern necessary regarding viruses in effluent reuse systems. By reducing the chance of human contact with the effluent, concern with viruses is minimized.

Irrigation with treated and disinfected unfiltered wastewater effluent has been practiced for years on New Providence Island, as well as other locations in The Bahamas, in settings similar to those on Cable Beach, with no public health or environmental related problems recorded. Furthermore, there were no reports found in the literature of public health or environmental related problems with similarly treated effluent reuse systems in the United States. Therefore, secondary treatment of the wastewater followed by chlorination was recommended for the Cable Beach reuse irrigation system, except for those areas directly adjacent to the casino and hotels where people are likely to come in direct contact with the irrigation spray and/or aerosols when irrigating during early morning hours.

Irrigation water for those areas near the casino and hotels will be taken from the flushing water system prior to dye injection. This will result in a minimal additional expenditure needed to increase the capacity of the filters and will provide insurance against the possible spread of waterborne diseases.

The remaining portion of the effluent intended for landscape irrigation will flow to an existing nearby pond after chlorination. By locating the irrigation pumping station on the opposite side of the pond from incoming effluent, maximum detention time in the pond and exposure to sunlight will be achieved. This will further increase bacteria reduction. Screening will be used on the pumping station suction intake to remove solids which tend to harbor bacteria and sometimes clog sprinkler heads. The addition of chlorine prior to pumping will further protect against detrimental effects of the reuse system.

Precautionary measures will be taken to reduce the chance of direct human contact with the irrigation effluent and its aerosols; thus, minimizing any concern over viruses. These precautionary measures include spraying during the very early morning hours, location of sprinkler heads so that spray does not land directly on walkways, and the use of sprinkler heads with low trajectories to decrease aerosol carry-over.

Another factor considered was the salinity of the water to be used for irrigation. Various species of plants have limited tolerance for salinity and their growth may be inhibited by salinity concentrations as low as 500 to 1,000 mg/l. Plant tolerance to salinity is also dependent to a limited extent by the type of soil; sandy soil having a greater tolerance due to its drainability.

Wastewater salinity depends heavily on the salinity of the potable water supply. Normal domestic or commercial water use usually adds about 300 mg/l salinity to the original water supply. Information available indicates that Nassau municipal water has a salinity around 1,000 to 1,100 mg/l. It is reasonable to expect the wastewater to have a minimum of 1,300 to 1,400 mg/l salinity, and more if local well water gains access to the wastewater system. Thus, it is likely that wastewater plant effluent can be used to irrigate only the more salt-tolerant plants.

The reuse of wastewater effluent for toilet flushing tends to further concentrate salinity. If one-half of the wastewater effluent is returned for flushing and each use adds and equivalent of 300 mg/l salinity, the ultimate steady-state salinity concentration in effluent used for irrigation (and flushing) will be 1,700 mg/l for a 1,100 mg/l water supply. Bermuda grass, which is used on the golf course fairways, has fair to good salt tolerance and, with leaching from rainfall, it is not expected that the grass will be adversely affected.

Creation of groundwater pollution by wastewater reuse in the area was also considered. A portion of a hotel potable water supply is supplied by wells located on the fringe of the golf course area to be irrigated with effluent. Over the years this area of the golf course has been irrigated by effluent from a small package treatment plant. The water quality of these wells is regularly tested and there has been no detrimental impact reported on the quality of the water.

A very small portion of the irrigated effluent may neither evaporate nor be consumed by the plants but will instead drain through the soil and eventually reach the water table. Depth to the water table at the irrigation sites is approximately 6 feet below the surface, although actual variation may be from 3 to 10 feet depending on the season and on location within the site.

Based on a good quality treated effluent, a small amount of BOD and SS will be applied to the ground during irrigation. This small amount of organic material should not affect either the turf or the soil system. Furthermore, intermittent irrigation at night and drying during the day will encourage the oxidation of any organic material. The concentration of suspended solids should be further reduced in natural percolation and filtration through the soil without causing clogging. Therefore, the overall treatment is anticipated to produce negligible concentration of BOD and SS by the time the effluent reaches the water table and is diluted.

The concentration of nutrients such as nitrogen and phosphorus, which are required by plants for growth, will depend on several factors. Bermuda grass requires an appreciable amount of nitrogen and a moderate amount of phosphorus. Based on the high degree of treatment and the absorption of these nutrients by Bermuda grass, a reasonable concentration of these elements in the effluent reaching the groundwater is estimated at less than 5 mg/l before dilution.

In view of the proposed high degree of wastewater effluent quality, additional treatment by land application, and dilution with the groundwater, detrimental contamination of the potable water supply is not expected. In order to add assurance that the wells will not be contaminated, no effluent irrigation is recommended next to water supply wells. A buffer zone of 100 feet from the well field was recommended.

Reuse for Toilet Flushing

Treated wastewater reused for toilet flushing should be reliably disinfected because it will be piped into hotel bathrooms where guests and employees may inadvertently come in contact with it. The flushing water should also be essentially free of suspended solids which would detract from its appearance in toilet bowls. To assure reliable treatment, the wastewater should first receive secondary treatment and filtration through fine grained filters of the type used in water treatment. This results in the removal of a major portion of the remaining suspended solids which decreases the number of bacteria and viruses to be disinfected. Disinfection will be by chlorination.

Treated and disinfected effluent will be stored at the wastewater treatment plant site in a lined reservoir of earthen construction. Flushing water will then be pumped to storage tanks provided within each building. Dye addition to flushing water will be conducted at each facility building so that it is evident that the water is not of potable quality.

DISPOSAL OF TREATED EFFLUENT

In the event of extended rainfall periods such that irrigation is not necessary or if a temporary upset in the treatment process renders effluent quality unacceptable for reuse purposes, a means of effluent disposal must be available. There are many methods of effluent disposal. Some of these include dilution in receiving waters, evaporation, discharge on land, and disposal wells. Of these disposal methods, only discharge on land and disposal wells were considered appropriate for the study area.

Effluent Disposal on Land

Effluent disposal by discharge on land may be accomplished by using the portion of the irrigation system away from the hotel and casino lawns and gardens. This method of disposal is intended for rainy periods when irrigation is not necessary and when effluent meets the level of quality specified for irrigation.

Application rates should be limited to levels which allow the sprayed water to percolate into the soil and not run off. The application rates should also be adjusted to suit the intended grass cover of the area.

Effluent Disposal by Disposal Well

A disposal well is recommended in the vicinity of the wastewater treatment plant site. The disposal well will be used during periods when the amount of effluent exceeds the amount needed for flushing and irrigation and when discharge on land via the irrigation system is not acceptable. The disposal well will also be used in the event that treated water may not be reused or disposed of on land due to unacceptable effluent quality. The disposal well will be constructed in accordance with the requirements of the Bahamas Building Code.

SUMMARY

Limited local water resources and increasing consumption create a situation on New Providence Island, The Bahamas where wastewater reuse deserves a high priority; especially at tourist resorts where the average per capita consumption is roughly five times that of the domestic consumption. Projects such as the resort complex underway on Cable Beach reflect the acceptance and encouragement of carefully planned wastewater reuse systems through such methods as landscape irrigation and toilet flushing by means of a dual plumbing system.

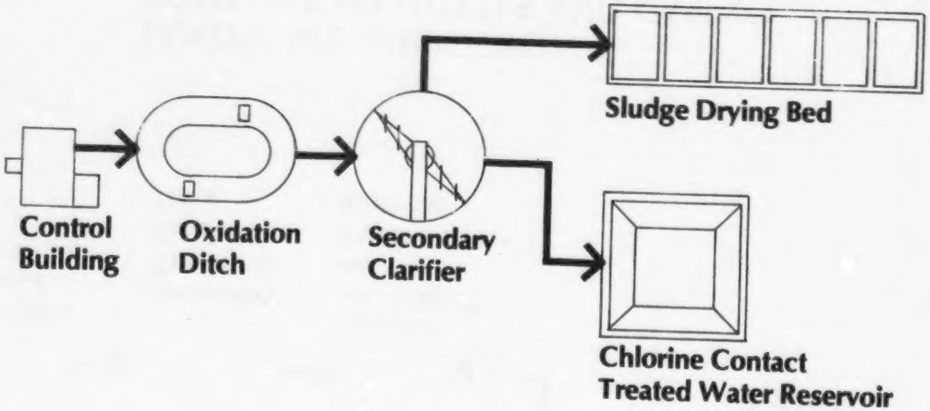

Control Building
Oxidation Ditch
Secondary Clarifier
Sludge Drying Bed
Chlorine Contact Treated Water Reservoir

Figure 1

FLOW SCHEMATIC OF BAHAMAS
SECONDARY TREATMENT PROCESS

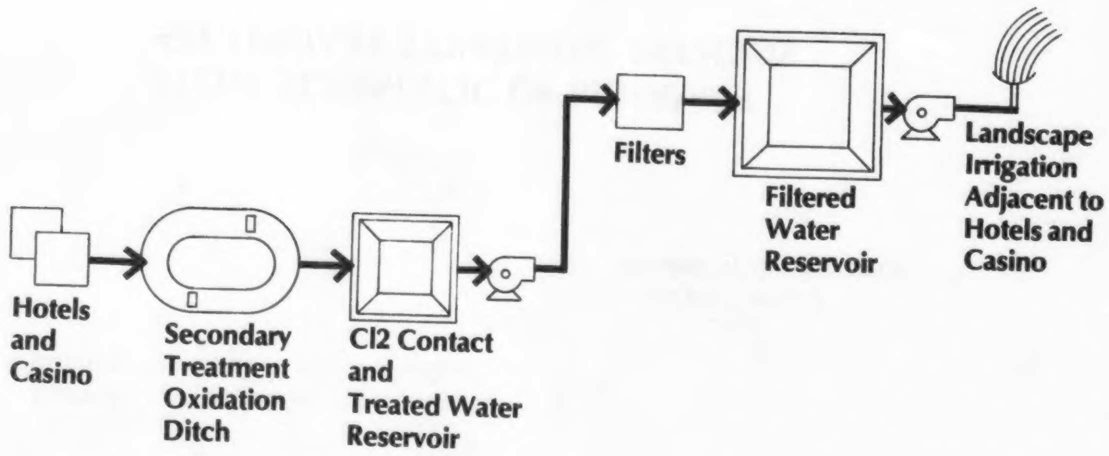

Hotels
and
Casino
Secondary
Treatment
Oxidation
Ditch
Cl2 Contact
and
Treated Water
Reservoir
Filters
Filtered
Water
Reservoir
Landscape
Irrigation
Adjacent to
Hotels and
Casino

Figure 2

LANDSCAPE IRRIGATION
ADJACENT TO HOTELS AND CASINO

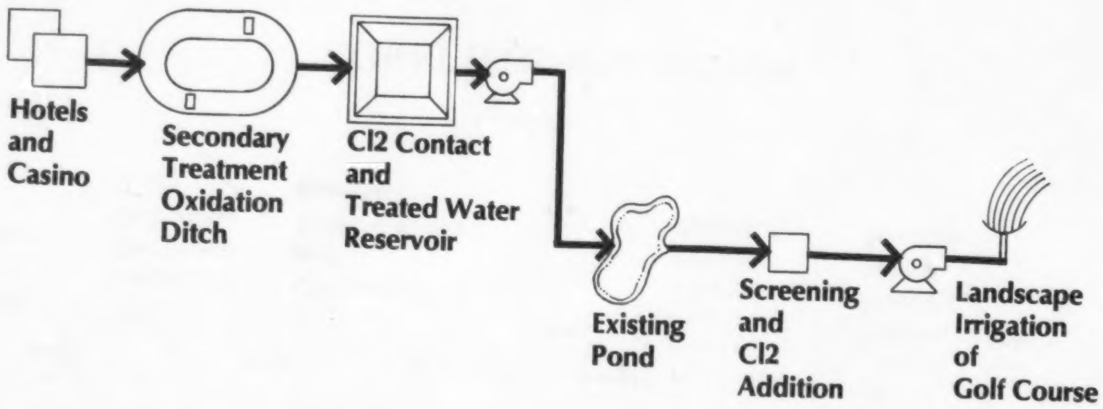

Hotels
and
Casino
Secondary
Treatment
Oxidation
Ditch
Cl2 Contact
and
Treated Water
Reservoir
Existing
Pond
Screening
and
Cl2
Addition
Landscape
Irrigation
of
Golf Course

Figure 3

LANDSCAPE IRRIGATION
OF GOLF COURSE

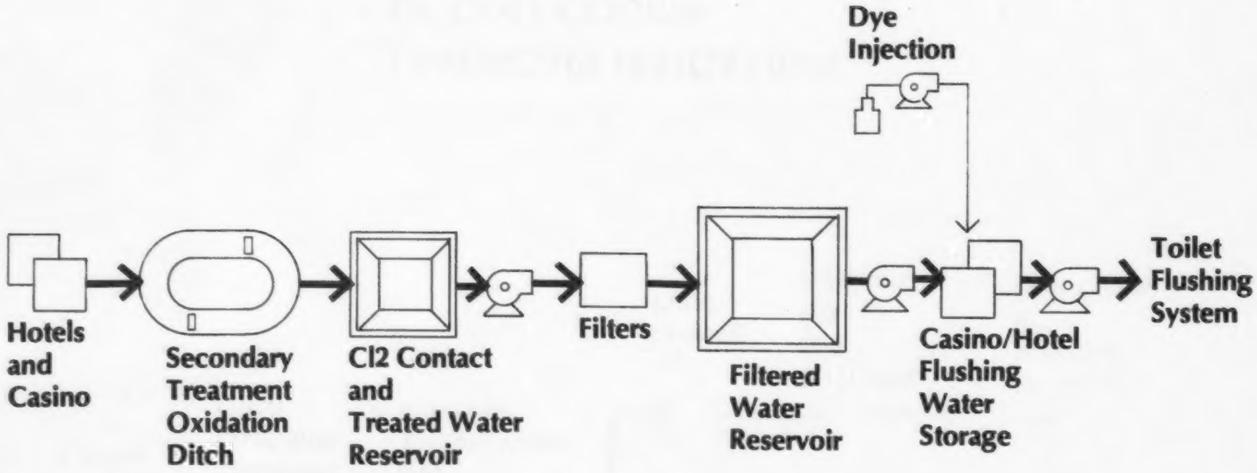

Dye
Injection
Hotels
and
Casino
Secondary
Treatment
Oxidation
Ditch
Cl2 Contact
and
Treated Water
Reservoir
Filters
Filtered
Water
Reservoir
Casino/Hotel
Flushing
Water
Storage
Toilet
Flushing
System

Figure 4

TOILET FLUSHING SYSTEM

PB82-223389

GROUNDWATER RECHARGE FROM AREAS IRRIGATED WITH MUNICIPAL WASTEWATER

Joseph S. Cebula
Head
Institute for Land Reclamation and
Grassland Farming, Wrocław Division
Powstańców Śląskich 98, 53-333 Wrocław

Edward S. Kempa
Professor and Dean
Department of Sanitary Engineering
Technical University
50-370 Wrocław, Poland

ABSTRACT

The results are presented of analyses and studies concerning ground water levels in sewage-irrigated area of the Wroclaw sewage farm. Great importance is stressed of agricultural utilization of sewage for improving water conditions in regions of substantial water deficiency. A good quality of this groundwater suggests the possibility of its application even for household purposes.

INTRODUCTION

Two fundamental problems should be posed when any practical sewage utilization and water replenishment are considered:

1. Is such a utilization of sewage technologically feasible and economically justified?
2. Is it possible to satisfy all the conditions concerning the quality of the product (i.e. the recovered water) including the sanitary requirements?

It is indispensable to answer the above questions since sewage is a complex mixture full of in components which are harmful to human and animal population. Based on the principles of the systems analysis, as described by Bishop [1] or Rich [8], it is also possible to use the algorithm developed by the author of this paper [6]. This algorithm includes all the essential requirements concerning the water quality as well as economic conditions (Fig. 1).

It has been well known for centuries that a successful biological wastewater treatment can be performed on natural soils and that the choice of irrigated fields and the mode of their use depend only on the unit hydraulic surface load and the wastewater concentration. These problems have been repeatedly considered as a set of decisions over several last decades, mainly due to changing conditions of the system surrounding. Depending on those conditions, the priority is given either to the maximum utilization of water contained in sewage or to the utilization of nutrient components. The problems are considered from various points of view either that of sanitary engineers or that of farmers or that of experts of hygiene. In all cases the objective function has to be such as to satisfy all interested parties.

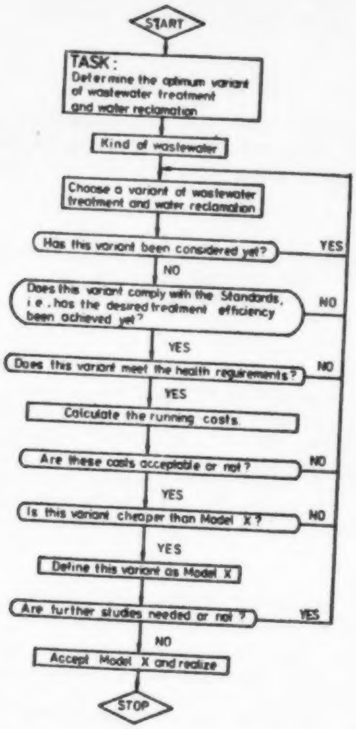

START
TASK:
Determine the optimum variant of wastewater treatment and water reclamation
Kind of wastewater
Choose a variant of wastewater treatment and water reclamation
Has this variant been considered yet?
YES
NO
Does this variant comply with the Standards, i.e., has the desired treatment efficiency been achieved yet?
NO
YES
Does this variant meet the health requirements?
NO
YES
Calculate the running costs.
Are these costs acceptable or not?
NO
YES
Is this variant cheaper than Model X?
NO
YES
Define this variant as Model X
Are further studies needed or not?
YES
NO
Accept Model X and realize
STOP

Fig. 1 Algorithm for determining the optimum variant of wastewater treatment and water reclamation [6]

Hence, much less attention has been given so far to the problems of the improvement of groundwater resources with sewage, purified to a high degree by passage through upper layers of soil and subsoil. It is by no means necessary that wastewater drains directly to the next water body.

The problems of groundwater recharge were chosen as the subject of this paper and the main attention will be given not so much to the quantitative water balance as to the quality and composition of the treated wastewater. Here, it would be more proper to speak rather of the reclaimed water.

Poland, although situated in the region of moderate climate (northern geographic latitude 49°0' to 54°50' and eastern longitude 14°07' to 28°08'), has a rather strained water balance, considering the needs of population and industry. Available water resources are the lowest all over Europe and amount only to 4.5 m^3/cap.d. This value is only slightly higher than that for the (semi) arid Egypt (Fig. 2).

A decrease of available groundwater resources is often due to the rapid removal of excess precipitation through the

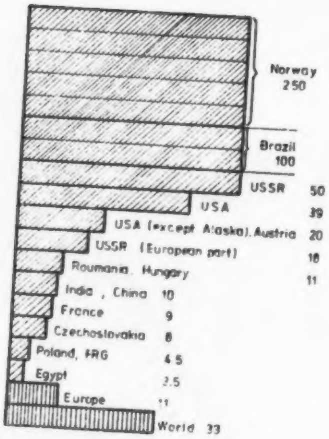


Fig. 2 Water availability in some countries (m^3/cap.d)

water melioration systems. This results in the lowering of groundwater level and, in consequence, in an additional lowering of flow levels during periods of draught, as then the rivers are fed almost exclusively by groundwaters.

Irrigation with sewage has a stabilizing effect on low flow levels. It should be also mentioned that in Poland sewage and some kinds of industrial wastewaters are used for agricultural purposes at about 50 farms. The surface area of the irrigated land covers some 30,000 hectares. The annual volume of the treated wastewaters amounts to 600 milion cubic meters. Some portions of the treated wastewaters enter the underground water course and there is no need for the direct re-use. The effluent from the drains is directed to fish ponds in one instance.

WROCLAW SEWAGE FARM

The sewage farm of Wroclaw is the largest object of this type in Poland as well as the only one being exploited for such a long period of time. It was designed and built in the 1890s; then it was expanding as the city grew to reach at present the area of about 1,500 hectares. The expansion was accompanied by modernization, including the installment of facilities for preliminary treatment. The main complex covering about 1048 hectares is supplied at present with about 170,000 m^3/d of sewage. A few years ago, the fields of spray irrigation were opened for operation and now they decrease the load of the main complex (Fig. 3).

The land adapted for irrigation is situated on light and medium soils. The subsoil consists of fine sands, sands with gravel, and gravels. The non-permeable layer is at the depth of 10 - 20 meters.

The filtration coefficient of the aquifer layer is equal to 4×10^{-4} m/s. On the area of 1080 hectares mainly grassland (meadows and pastures) are irrigated. Sewage used for

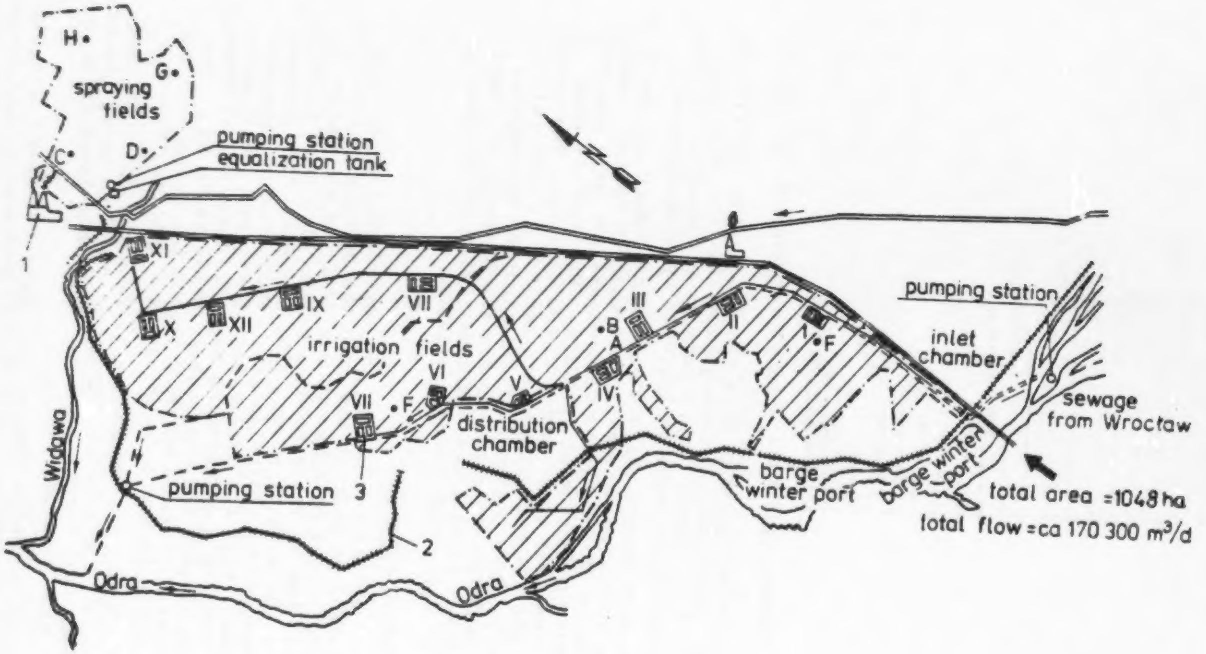

H
G
spraying fields
C
D
pumping station
equalization tank
N
1
XI
X
XII
IX
VII
irrigation fields
VI
VII
F
3
V
distribution chamber
pumping station
2
Widawa
Odra
Odra
B
A
III
IV
II
I
F
pumping station
inlet chamber
sewage from Wrocław
barge winter port
barge winter port
total area =1048 ha
total flow =ca 170 300 m³/d

Fig. 3 Wroclaw sewage farm [5]

▬ ▬ ▬ delivery pipe, —— sewage ditch, – – – drainage ditch, – . – border of sewage farm, 1 – drying of green fodder, 2 – river embankment, 3 – settling tanks I-XII, A–H– points of drainage and ground waters sampling irrigation is mechanically treated in 12 two-chamber settling tanks (each chamber of 11,000 - 18,000 m^3 capacity) situated at the sewage farm along the main feeding collector. The average time of the chamber filling with sludge is from 4 to 5 years and the drying period (during summer) is 4 to 5 months. Over these long periods there takes place an almost total mineralisation of sludge. The dewatered and dried sludge is removed from the chambers and offered for sale. The empty chamber is made ready for the next cycle.

In the years 1967 - 1975, exhaustive studies were carried out on the variability of discharge and quality of the groundwater at the sewage farm. The studies revealed that irrigation with sewage has an advantageous effect not only on the variability of groundwater levels but also on water retention in the soil, particularly over periods of low precipitation. In this paper some selected fragments are presented of studies which confirm the thesis of great possibilities of utilizing the groundwater from areas irrigated with sewage.

PHYSICO-CHEMICAL CHARACTERISTICS OF MUNICIPAL SEWAGE

The values of majority of contamination indices for crude sewage from Wroclaw delivered to the farm are increased. The composition of the sewage is typical of the one from large cities and industrialized urban agglomerations. From the statistical analysis of the concentration of some components it follows, that the levels of organic contaminants vary considerably.

The research was mainly concerned with the presence of trace elements. Their concentrations are not very high, as shown in Table 1, with the exception of zinc whose concentration exceeds the limits acceptable for the agricultural use of sewage. Crude sewage from Wroclaw is not at present a serious source of pollution with heavy metals, however, it must not be discharged without treatment [5].

CHEMICAL COMPOSITION OF GROUND WATERS

A wide-spread application of sewage to the irrigation of crops more and more often disturbs the natural balance between the inflow and outflow of mineral components of ground waters and may result in their excessive salinity. The danger of salinity is quite real as the excessive salinity of soils is known to occur under Polish climatic conditions. However, the knowledge of salt migration across the profiles of various soils allow us to chose suitable methods of irrigation with sewage and thus to prevent the excessive mineralization of ground waters. The reliable way of protection is the use of small sewage doses corresponding to the water capacity of soils.

From the Polish studies on the salinity of ground waters, carried out in the years 1972 - 1975 at the Wroclaw sewage farm irrigated with wastewater for more than 70 years it follows, that the salt concentration at shallow levels of ground waters varied annualy to a relatively small extent. It may be then assumed, that the salinity has stabilized after such a long period of irrigation and at present it

Table 1 Pollution index of sewage used for irrigations

Index	Unit	Raw sewage	Treated sewage
pH		6.5 – 7.7	7.3 – 7.5
acidity	mval/dm^3	0.0 – 1.0	0.4 – 0.6
alkalinity	mval/dm^3	3.4 – 10	3.3 – 3.4
BOD_5	mg O_2/dm^3	160 – 320	110 – 116
PV	mg O_2/dm^3	180 – 240	57 – 74
COD	mg O_2/dm^3	967 – 1237	191 – 294
chlorides	mg Cl/dm^3	142 – 200	156 – 168
conductivity	µS/cm	1560 – 2000	1650 – 1890
total solid residue	mg/dm^3	1061 – 1721	914 – 1001
total soluble compounds	mg/dm^3	689 – 870	726 – 785
total suspended matter	mg/dm^3	372 – 851	186 – 228
sulphates	mg SO_4/dm^3	147 – 192	172 – 215
N total	mg N tot/dm^3	45.3 – 50.9	41.9 – 45.3
N organic	mg N org/dm^3	15.8 – 19.1	13.9 – 14.0
P total	mg P/dm^3	8.1 – 19.3	12 – 15.1
Na	mg Na/dm^3	83 – 195	–
K	mg K/dm^3	25 – 43.5	–
Ca	mg Ca/dm^3	135 – 185	–
As	mg As/dm^3	0.001 – 0.076	–
Hg	mg Hg/dm^3	0.4 – 2.0	–
B	mg B/dm^3	0.13 – 0.24	–
Ag	mg Ag/dm^3	0.001 – 0.005	–
Cu	mg Cu/dm^3	0.11 – 0.57	–
Ni	mg Ni/dm^3	0.06 – 0.15	–
Zn	mg Zn/dm^3	1.07 – 2.80	–
Pb	mg Pb/dm^3	0.02 – 0.1	–
Cd	mg Cd/dm^3	0.012 – 0.100	–
Mn	mg Mn/dm^3	0.10 – 0.35	–

amounts to 600 - 800 mg/l within the area of sewage farm. The salinity of ground waters decreases rapidly with the increasing distance from irrigated fields [4,9].

Table 2 presents examples of the concentrations of principal physico-chemical components of ground and drainage waters. measured with the use of a system of piezometers and wells. Because of the size and character of the Wroclaw sewage farm, the data obtained may be considered representative of this kind of wastewater treatment under the similar climatic conditions.

SANITARY CONDITIONS OF GROUND WATERS

Field and lysimetric tests demonstrated that the upper soil layer (0 to 25 cm) being most active biologically, retains from 90 to 99 per cent of bacteria from the wastewater. Further down the count of Escherichia coli is reduced to zero. However, microbiological studies of ground waters at the Wroclaw sewage farm revealed the presence of psychrophilic bacteria (25 °C). Bacteria belonging to this group are not directly harmful to man but their presence indicate a fertile environment and hence the appearance of other bacteria is probable.

As far as mesophilic bacteria (37 °C) are concerned, they were found to occur in groundwaters in amounts of 20 to 30

Table 2 Range of mean concentrations of physicochemical values of ground and drainage waters within the sewage farm of Wrocław

Index	Piezometers on sewage farm	Piezometers on non-irrigated fields	Deep-wells on sewage farm	Wells outside the irrigated field	Drainage waters
solid residue, mg/dm^3	838–1228 (959)*	391–6383 (1590)	601–887 (719)	601–1484 (1097)	669–785 (713)
dry weight, mg/dm^3	527–818 (657)	361–5534 (1271)	370–649 (491)	384–915 (764)	320–489 (414)
alkalinity, mv/dm^3	4.1–7.9 (5.7)	1.3–13.1 (4.6)	3.1–6.1 (4.5)	2.0–5.3 (3.6)	5.1–7.2 (6.7)
PV, mg/dm^3 O_2	3.7–39.4 (14.4)	2.5–29.1 (10.06)	3.0–5.5 (4.1)	3.2–25.5 (8.8)	4.1–14.7 (8.1)
N total, mg/dm^3	4.8–24.3 (14.9)	1.6–19.8 (8.03)	2.6–18.1 (6.8)	2.3–8.5 (5.1)	4.5–16.1 (8.4)
nitrates, mg/dm^3	0.61–18.8 (5.6)	0.09–18.1 (3.24)	0.14–3.66 (1.2)	0.14–72.0 (33.95)	0.23–0.44 (0.37)
chlorides, mg/dm^3	121–156 (138)	26–154 (92)	83–144 (120)	51–171 (112)	79–118 (92)
sulphates, mg/dm^3	108–270 (194)	105–269 (194)	144–237 (175)	130–339 (206)	111–165 (144)
K, mg K_2O/dm^3	13–28 (19)	3–191 (37)	4–22 (10)	8–210 (90)	3–5 (3)
P, mg P_2O_5/dm^3	0.02–0.28 (0.17)	0.03–0.43 (0.12)	0.04–0.11 (0.08)	0.04–0.90 (0.27)	0.05–0.11 (0.08)
Fe, mg/dm^3	0.25–13.3 (3.02)	0.10–15.2 (4.94)	0.43–13.6 (4.02)	0.004–7.8 (1.29)	0.09–2.02 (0.84)
Mn, mg/dm^3	0.12–1.31 (0.50)	0.08–2.56 (0.75)	0.09–0.96 (0.39)	0–0.50 (0.22)	0.1–0.47 (0.27)
pH	7.0–7.2	–	–	–	6.9–7.1
conductivity, μs/cm	900–1215	–	–	–	765–915

* In brackets there are mean values of mean concentrations

colonies per mililiter. The test of Escherichia coli was also positive and measured values of the titer varied from 10 to 50, sporadically they exceeded 50. According to Polish drinking water standards, such water can be supplied to individual househols and in some cases to small cities of population below 50,000 [2].

GROUND WATER RESOURCES

The analysis of water levels was based on the data collected at 12 sites (piezometers and deep wells) situated on the irrigated and non-irrigated areas. The highest water level in relation to the lowest on recorded in a piezometer during the observation period was taken as a basis for analysis as well as the monthly amplitudes of water levels [3].

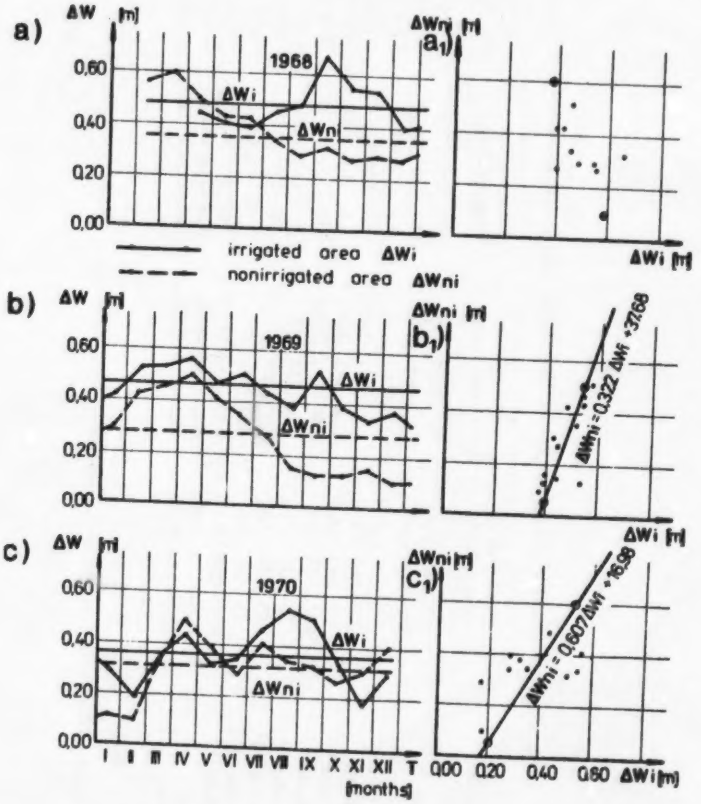


Fig. 4 Range of groundwater levels on irrigated areas and correlation between them [7]

Examplary variations in the ground water levels are given in Fig. 4. The comparison of a year of lower precipitation

(1969) with the one of higher precipitation (1970) shows the effect of precipitation on the values of the correlation and linear regression factors. The correlation factor decreases while the linear regression coefficient increases with the increasing precipitation. From the periodical course of rises in ground water levels it follows, that the effect of irrigation with sewage is most prominent in the second half of the year (June-December) and no effect is observable during spring months.

Worth noticing is also the frequence distribution of the occuring of extreme water levels during the year. Regardless of the amount of precipitation, the extreme levels occur the whole year round on irrigated areas while on non-irrigated areas the occurence of extreme states depends mainly on the distribution of precipitation and on water reserve remaining from the previous year. In a year of low precipitation, the maximum levels on irrigated areas occur in spring (March, April, May) while minimum levels, in the fall and winter time.

Based on the studies and observations discussed, it may be concluded that there is a possibility of improving the water balance of areas characterized by water shortage by their irrigation with sewage.

USABILITY OF GROUND WATER FROM IRRIGATED AREAS

The application of irrigation with municipal sewage to replenish communal water sources is known from practice. For instance, this method of feeding the municipal water intake system has been used since 1954 at Bielefeld, a city in West Germany of over 200,000 population. In Bielefeld, preliminary treated sewage (about 5 million cubic meters per year), is applied to arable land, pastures and meadows situated in close vicinity of the aquifer. In addition to significant agricultural effects, such as higher yields from arable land and meadows, there were achieved also higher and more stable water levels at the sites of municipal intakes.

SUMMARY

The following positive conclusions can be drawn from the results of complex studies carried out at the Wroclaw sewage farm:

1. Ground waters on areas irrigated with sewage may play a significant role as an additional source of usable water.
2. Due to constant replenishment, ground waters from areas irrigated with sewage are the better water source than surface waters.
3. Under the favourable geological conditions (great thickness of the aquifer layer) ground waters on irrigated areas can be considered an underground reservoir which can serve as a stabilizing reservoir in periods of a varying demand for water. Such hydrogeological conditions prevail at the Wroclaw sewage farm.

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PB82-223397

RECLAMATION OF WASTEWATERS AND DEGRADED RIVER WATERS BY ADVANCED WASTE TREATMENT IN HONG KONG

William R. Everest
Vice President

PRC Toups, Consulting Engineers
972 Town & Country Road
Orange, California 92668

Hong Kong, located at the mouth of the Pearl River Estuary, includes a mainland area, two large islands, and over one hundred small islands within its boundaries. The total land area of about 400 square miles, most of which is steep and rugged, contains over 5 million people. The majority of this population is located on both sides of Victoria Harbor on Kowloon Peninsula and Hong Kong Island. This urban area is one of the most densely populated in the world. There are no perennial large rivers or natural lakes in Hong Kong, and water supply has been a major problem since the City was founded in the mid-19th Century.

HONG KONG WATER RESOURCES

The water resources of Hong Kong are derived from two sources: rainwater catchments (including reservoir sites on land and two impounding sites reclaimed from the sea) and importation from mainland China. In 1977, flash distillation of seawater was initiated and proceeded for nearly one year. Past shortages of water resources have necessitated the restriction of water usage to reduce the draw-off from the system during the dry years of 1963, 1967 and 1976. Hong Kong is presently experiencing another severe dry year, and it has been necessary to re-activate the seawater distillation plant, and water usage restrictions are again being considered. The extensive local catchment resources are fully utilized. The Hong Kong Government has recently contracted for additional imported supplies from mainland China at a favorable cost. However, the extensive construction of transmission and treatment facilities to utilize this source cannot be completed in time to meet current water demands. Other potential supplies are being studied by Hong Kong as part of an overall program to investigate alternative future water resources.

The reclamation of available degraded river water and treated wastewater effluent, and reverse osmosis desalting of seawater and brackish water have been identified as possible sources of municipal and industrial supply for Hong Kong. In December 1978, PRC Toups was selected as consultant by the Hong Kong Water Supplies Department to formulate and implement pilot plant test programs to establish: 1) the feasibility of reclaiming fresh water from domestic wastewater and stream water of substandard quality using applicable advanced treatment processes; 2) the suitability, reliability and performance of various advanced wastewater treatment processes and different levels of treatment; 3) the feasibility of desalting seawater and brackish water at various locations by reverse osmosis and appropriate pretreatment; 4) the suitability, reliability, performance, and other operational characteristics of commercially available reverse osmosis membranes; 5) the technical and economic viability for full-scale application of the processes.

Separate pilot plant facilities for reclamation and reverse osmosis desalting were designed, fabricated, and installed by mid-1979. Following start-up and operator training, the AWT pilot plant test program was initiated in November 1979. Operations data have been collected daily by Hong Kong Water Supplies Department operations staff and evaluated by PRC Toups. The following sections focus on the AWT pilot plant and test program and discuss the results of the AWT program and the technical viability and economics for full-scale water reclamation.

AWT PILOT PLANT

An analysis of goals for the AWT pilot plant program immediately indicates that the plant must be extremely flexible and have near-universal capabilities. Three different types of water in the plant must be treated to various levels of effluent quality. Table 1 presents a water quality summary for the three source waters to be treated. As shown, there are considerable differences in the quality of the three. The pilot plant must be capable of successfully treating this wide range of waste qualities. In addition, effluent water quality requirements have not been established at a single level because of the potential variety of reuse applications. The effluent quality requirements stipulate treatment varying from partial tertiary to a level providing greater than 95 percent removal of such constituents as BOD, suspended solids, nitrogen, and phosphorus, in addition to effluent which is essentially free of bacteria and viruses. Thus, a clear contrast exists between the design of this pilot plant and most situations where design can be developed based on specific effluent water quality or discharge requirements. Without definitive effluent requirements, and with three distinct waters to be treated, a single set of optimum processes is difficult to select.

A methodology for evaluating and selecting unit processes for the pilot plant included such factors as compatibility with existing secondary treatment schemes, land requirements, reliability, ease of operation, flexibility, stability, energy requirements, and overall costs. This resulted in a final selection of three distinct process trains plus three effluent polishing processes. The three test process trains in the pilot plant include: physical-chemical treatment (Train I), fixed growth biological treatment (Train II), and combined suspended/fixed growth biological treatment (Train III). The three process trains are capable of operating either independently of each other or, in some cases, in a series. Feedwater to Trains I and II can be either wastewater previously provided secondary treatment or raw stream water. Train III is designed to treat primary treated wastewater only. Effluent from each of the process trains can be fed to the polishing processes. Figure 1 presents the unit processes used in the various process trains. Because the pilot plant is a test facility, a nominal design capacity was not selected. However, the various unit processes are capable of being operated at flows ranging from 1 to 25 gpm. Each of the process trains combined with the effluent polishing processes are capable of being operated to achieve the wide variety of effluent quality goals required of the pilot plant.

Train I consists of chemical addition of lime, alum, ferric chloride or polymer, followed by rapid mixing, flocculation and clarification for suspended solids, phosphorus, and partial dissolved organics removal. In the case of lime addition, downstream treatment includes an ammonia stripping tower for nitrogen removal under high pH conditions with subsequent recarbonation by CO_2 addition for pH reduction and dual media gravity filtration for residual solids removal. When alum or ferric chloride is used instead of lime, the clarifier effluent bypasses the ammonia stripping tower and recarbonation process, and is discharged directly to the filters.

The unit processes in Train II include a rotating biological contactor (RBC) for both nitrification of ammonia, followed by fixed growth submerged gravity filters for both nitrogen removal by denitrification and residual solids removal. An external carbon source such as methanol is added prior to the filters to accelerate the denitrification process. Train II can be used to treat river water, secondary effluent directly, or can be fed effluent from the Train I clarifier if treatment for phosphorus removal is desired. Acid or alkalinity can be added as necessary to the RBC influent for control of pH or alkalinity buffering.

Process Train III is designed to provide treatment to primary wastewater effluent and consists of a suspended-growth reactor, clarifier and denitrifying filters. The suspended-growth reactor can be operated in a number of ways and allows for testing of various suspended-growth systems. Initially, the reactor was operated as an activated sludge tank providing both oxidation of carbonaceous matter and nitrification. Alkalinity can be added to the tank influent to provide sufficient buffering for nitrification. A coagulant can be added at the effluent end of the tank for phosphorus removal in the downstream clarifier. Denitrification for nitrogen removal and residual solids removal is provided in the subsequent submerged-gravity filters identical to those in Train II. Train III can be modified to be operated as an alternating contact process for combined biological removal of carbonaceous BOD, nitrogen, and phosphorus.

Effluent from any of the three process trains can be treated further by three effluent polishing processes. Granular activated carbon columns provide removal of residual organics by adsorption. The unit processes of chlorination and ozonation allow for final disinfection of the flowstream. The two disinfection processes can be operated either in series or in parallel with the activated carbon columns.

AWT TEST PROGRAM

The test program for the pilot plant has been developed to allow for evaluation of unit process and process train performance by parametric testing of operating conditions. Parametric testing allows for assessment of a full range of treatment efficiencies by systematically varying operation conditions, a necessity in view of the lack of a single set of effluent quality requirements. A summary of the parametric test program is provided in Table 2. Because of the relatively short initial test period for the project, a complete testing of all parameters which affect process performance is not practicable. Thus, only those parameters which have the most significant impacts on process performance could be included in the test program. The test parameters in some cases are controlled by changing physical operating conditions of the plant, e.g. clarifier hydraulic loading by changing effluent flow. Others vary with water quality of the influent to the process and cannot be readily controlled, e.g. temperature. However, the parameters being tested permit the fullest possible evaluation of process performance within the time constraints of the project.

Of particular note in the test program are certain components which are not generally included in a standard pilot plant test program. These include provisions for future testing of alternating contact treatment systems, evaluating the use of local brewery wastes as a cost effective carbon source for denitrification, and extensive virus testing. These particular items have been incorporated into the general test program in response to the specific concerns of relatively high costs of AWT processes and protection of public health in reusing wastewaters.

Hong Kong has few natural resources and must import all its energy supplies and most materials such as chemicals. Therefore, treatment processes which conserve energy and minimize the need for chemicals are especially desirable. Alternating contact systems, such as the Bardenpho process, offer the advantage of obtaining high levels of BOD, nitrogen and phosphorus removal without using costly chemicals.

For similar reasons, wastes from a local brewery have been tested as a potential carbon source for aiding denitrification in the submerged filters of Trains II and III. The use of brewery wastes in lieu of an expensive fuel derivative such as methanol could result in significant cost savings and energy conservation in a full scale facility.

Viruses in wastewater are a major concern for public health reasons in any reuse application where public contact is possible. Accordingly, the pilot plant program has incorporated virus testing of potential source waters and process train effluents to determine the potential problems from viruses.

TEST PROGRAM RESULTS

The parametric test program outlined in Table 2 was initiated in November 1979 for Trains I and II. Train III was installed several months after Trains I and II and began operating under test conditions in early 1980. For the effluent polishing processes, operational problems with both treatment and laboratory equipment resulted in irregular operation and water quality data collection.

Several conclusions have been drawn from analysis of the results of the test program, based upon operations through November 1980. Since the purpose of the test program is to establish the technical viability of the treatment processes, the analysis is directed towards the verification of demonstrated treatment technology to Hong Kong source waters rather than the development of new theories and treatment processes.

Phosphate removal efficiencies of greater than 95 percent were achieved by rapid mixing, flocculation, and clarification with lime for both river water and secondary effluent at lime doses greater than 400 mg/l and 300 mg/l, respectively. Ninety percent removal of phosphate from secondary effluent was obtained with both alum at doses ranging from 73 mg/l to 164 mg/l and ferric chloride at doses of 61 mg/l to 65 mg/l. Suspended solids removal with lime was not consistently achieved for either source water although the nature of the suspended matter was changed from brown or black organic and inorganic solids to calcium carbonate pin floc, indicating removal of influent solids. Alum and ferric chloride addition to secondary effluent provided suspended solids removals greater than 60 percent.

Ammonia stripping results compared favorably with results attained at full-scale facilities when differences in design and operating conditions such as tower packing depth are taken into account. Process efficiency was demonstrated to improve with higher pH, increased countercurrent air loading, increased temperatures, and reduced hydraulic loading. Average ammonia removal efficiencies up to 71 percent and 92 percent were achieved for various test runs for river water and secondary effluent, respectively. The test results indicate that ammonia removal efficiencies in excess of 90 percent may be achievable for both source waters provided proper pH levels, temperature, hydraulic and air loading, and tower packing depth are maintained.

Carbon dioxide requirements for pH reduction by recarbonation were generally lower for secondary effluent than for river water due to the relatively lower alkalinity of the former during the test program. No attempt was made at evaluating the performance of the recarbonation system as the process is well understood and design principles well-documented. The process was operated only to provide a stabilized water for the filtration system.

The tests results for the filtration process generally indicate that filtrate suspended solids concentrations of less than 10 mg/l are achievable for both river water and secondary effluent subsequent to chemical clarification, provided influent suspended solids concentrations are less than 25 mg/l to 30 mg/l. The test results also indicate that variations in hydraulic loading from 1.0 Igpm/ft^2 to 6.7 Igpm/ft^2 did not significantly impact filtrate suspended solids quality over the concentration ranges previously mentioned. Test results of direct filtration of river water with low dose alum addition indicate that filtrate turbidities were higher than that achieved by filtration following lime clarification, ammonia stripping, and recarbonation for the same range of influent turbidities. Average filtrate turbidities less than 15 TU were not achieved by the direct filtration tests over a range of alum dosings of 0 mg/l to 10 mg/l and hydraulic loadings of 1.7 Igpm/ft^2 to 8.3 Igpm/ft^2.

The performance of the rotating biological contactor varied during the test program. Initial nitrification efficiency in treating secondary effluent was less than predicted with efficiencies less than 80 percent. However, subsequent tests with alum clarified secondary effluent provided average nitrification efficiencies of greater than 90 percent. Subsequent treatment of primary effluent provided nitrification efficiencies of greater than 70 percent. Treatment of river waters provided nitrification efficiencies greater than 70 percent with two specific runs obtaining efficiencies greater than 90 percent. The fact that the 90 percent removal efficiencies were eventually achieved indicates this level of performance can be achieved by the rotating biological contactor in treating Hong Kong's wastewater effluents and river waters.

Test results of the denitrifying filters on secondary effluent subsequent to the rotating biological contactor indicate consistently high average nitrate removal efficiencies of greater than 90 percent were achieved using methanol in doses greater than 3.9 mg per mg nitrate nitrogen and at hydraulic loadings up to 1.8 Igpm/ft^2. Filtrate suspended solids concentrations less than 10 mg/l were achieved at influent suspended solids qualities of 20 mg/l or less over a wide range of hydraulic loadings. Comparative testing of brewery wastes and methanol as biodegradable carbon sources for denitrification indicated that methanol was technically more effective for the denitrification process than brewery wastes. Effluent nitrate concentrations were lower for methanol as were filtrate suspended solids. Brewery wastes were also noted to cause an increase in suspended solids concentrations due to the high suspended solids content of the brewery wastes. However, as the cost of brewery wastes are likely to be significantly less than methanol, their use may be cost-effective in applications where required nitrate removal efficiencies are less than 90 percent or in two stage systems with first stage brewery waste addition and second stage methanol addition.

Operational problems and delay in startup of the initial test program resulted in inconclusive results for the activated carbon process. Retesting with fresh carbon treating secondary effluent was subsequently performed. The results of the tests are difficult to interpret due to the relatively high hydraulic loading and correspondingly low contact time maintained during the test. A general decline in adsorption capacity was noted with time and treated volume. Breakthrough was noted at 0.10 lb TOC removed/lb carbon after approximately 96,000 Igal at a carbon bed depth of 3.5 ft. However, breakthrough was not experienced at subsequent sampling depths. An adsorption capacity greater than 0.10 lb TOC removed/lb carbon was experienced at the 7.0 ft depth. The remaining sampling depth did not attain adsorption capacities of 0.10 lb TOC/lb carbon prior to the completion of the test, and, because breakthrough was not achieved, cannot be used to verify the adsorption capacity of the carbon.

Inactivation rates of coliform bacteria and effluent coliform concentrations from the chlorination process varied widely under similar conditions of contact time, sodium hypochlorite dose, temperature, pH, and other parameters. Selected test data indicates that effluent coliform concentrations of less than 200 MPN/100 ml were achieved. It is believed that the inconsistent test results are specific to the pilot tests and not to the process in general and that effluent coliform concentrations of less than 200 MPN/100 ml can be consistently achieved by full-scale chlorination facilities.

The ozonation test program was severely hindered by the failure of the ozonation equipment to function properly. Test results obtained after attempted repair of the equipment indicate that coliform inactivation rates varied significantly. Consistently high inactivation rates were not obtained despite extensive ozone feed and contact times. As the process has been successfully used for disinfection of wastewaters in full-scale facilities in Europe and the United States, the relatively poor test results are considered specific to the pilot plant tests and not to the process in general.

Seeding experiments were conducted on town water to allow controlled comparison of virus concentrating techniques and for comparison of virus removal by the disinfection processes. These standardization test results indicate that the detection limit of the concentration and assay procedures used in the test program is approximately 10 PFU/100 l. Testing of town water in control samples resulted in expected zero recoveries. However, background levels in river waters are relatively high and secondary effluent monitoring indicates a wide variation in virus concentration levels. Seasonal variation in the concentration of viruses in the river waters is also indicated.

Chemical clarification was demonstrated to be an effective treatment process in virus removal. Approximately 80 percent of the samples tested from the chemical clarification process had no detectable virus concentrations, whereas, in samples taken from treatment process trains not utilizing chemical clarification, only 25 percent had no detectable virus concentrations. No viruses were detected in the effluent of any pilot plant disinfection process, indicating their effectiveness in removal of viruses following previous treatment process.

The performance of the combined suspended growth nitrification process (Train III) during periods when influent quality approached levels anticipated in primary effluents at planned full-scale treatment facilities indicates that the system is technically feasible for Hong Kong. However, measured primary effluent quality is of relatively high strength and is of poorer quality than projected for future full-scale facilities. Testing carried out during the critical testing period indicates that the performance of the combined suspended growth nitrification system varied directly as a function of influent quality. Generally, process performance improved with improved influent quality. At average influent quality of 201 mg/l BOD_5, 47 mg/l ammonia-nitrogen, and 120 mg/l suspended solids, nitrification performance reached maximum with effluent qualities averaging 26 mg/l of BOD_5 (86 percent removal), 23 mg/l of suspended solids (81 percent removal), 1.0 mg/l of ammonia-nitrogen (98 percent removal), and 11 mg/l of nitrate-nitrogen. Performance rapidly declined at influent BOD_5 values of greater than 210 mg/l. Sludge settling characteristics were relatively poor. SVI values generally exceeded 200, while RAS MLVSS concentrations were less than 4,000 mg/l. Rising sludge, probably due to denitrification in the sludge zone of the clarifier, was noted a few days after maximum nitrification performance was achieved. During this period, clarifier effluent suspended solids concentrations reached levels greater than 500 mg/l due to solids carryover in the effluent. Sludge bulking may also have contributed to the poor settling performance throughout the test program. Further water quality monitoring and long term testing is necessary to fully evaluate the feasibility of combined suspended growth nitrification systems in Hong Kong.

FEASIBILITY OF FULL-SCALE RECLAMATION

As indicated previously, water quality criteria for reclaimed waters have not been established at a single level because of the potential variety of reuse applications in Hong Kong. Specific water quality criteria for reclaimed waters can only be established with detailed investigations of specific potential reclamation schemes. In lieu of such detailed studies, a range of water quality criteria have been presented for analysis in this program for reclaimed waters to be stored in reservoirs, diluted with waters from other sources, and treated by conventional water treatment processes prior to potable use. Three specific levels of reclaimed water quality criteria are presented representing a range from partial advanced treatment to very high levels of removal of key water quality constituents prior to reuse. The criteria include key water quality parameters and are as follows:

Level 1: BOD_5 = 15 mg/l, COD = 35 mg/l, TOC = 15 mg/l,
suspended solids = 20 mg/l, total nitrogen = 10 mg/l,
and total phosphate = 3 mg/l

Level 2: BOD_5 = 10 mg/l, COD = 25 mg/l, TOC = 10 mg/l,
suspended solids = 10 mg/l, total nitrogen = 3 mg/l,
and total phosphate = 1 mg/l

Level 3: BOD_5 = 10 mg/l, COD = 25 mg/l, TOC = 10 mg/l,
suspended solids = 10 mg/l, total nitrogen = 2 mg/l,
and total phosphate = 0.5 mg/l

Wastewater Reclamation

Based on the results of the pilot plant test program and an evaluation of existing treatment technology, both physical-chemical and biological treatment are considered technically viable for reclamation of secondary wastewater effluent to Level 1 and Level 2 reclaimed water quality criteria. However, only physical-chemical treatment is viable for Level 3 criteria, primarily due to the need to use lime clarification to meet the 0.5 mg/l total phosphate requirement.

A summary of cost estimates of full-scale reclamation of secondary wastewater effluent in Hong Kong is presented in Table 3. The cost estimates indicate that physical-chemical treatment is lower in total unit cost than biological treatment. Unit costs for a 50 mIgd biological treatment facility are approximately 54 percent and 33 percent greater for Level 1 and Level 2 reclaimed water quality criteria, respectively. The percentage difference in total unit costs between biological and physical-chemical treatment increases with capacity and decreases with increasing level of reclaimed water quality criteria.

The estimated unit costs of using methanol for denitrification in biological treatment of secondary effluent is HK $0.27/1,000 Igal and HK $0.42/1,000 Igal for treatment to Level 1 and Level 2 reclaimed water quality criteria, respectively. The use of brewery wastes in lieu of methanol could reduce the unit cost of biological treatment by the difference in cost between methanol and the brewery waste. Assuming a maximum potential cost savings equal to the unit cost of methanol, the total unit costs of biological treatment would remain greater than that for physical-chemical treatment. The unit costs of biological treatment would be reduced to 38 percent greater than physical-chemical treatment to Level 1 and 17 percent greater for treatment to Level 2 for a 50 mIgd facility.

River Water Reclamation

Variations in Hong Kong river water quality generally preclude the use of biological treatment processes for reclaiming those waters due to inability of micro-organisms to acclimate readily to changing environments. Physical-chemical treatment processes are more suitable for treating source waters that experience variations in strength or interrupted flows. However, treatment of river water to Level 3 quality is generally not considered technically reliable due to the variations in source water quality.

Estimated total unit costs for treating Hong Kong river waters for reclamation are presented in Table 4.

Treatment systems for reclamation of river waters must be designed for the poorest source water quality anticipated. During periods when source water quality is improved, the treated effluent can be blended with untreated flows that could not otherwise be reclaimed, thereby resulting in total flows of reclaimed water greater than the design capacity of the treatment process train. This reduces the net unit cost of the reclaimed water.

FUTURE PROSPECT FOR RECLAMATION IN HONG KONG

Negotiations between Hong Kong and China which began in December 1979 have led to execution of a contract for China to increase it's supply of water to Hong Kong beyond the current levels when required. The cost of this additional imported supply will be generally lower than other potential supplies being investigated by Hong Kong. Reclamation of river water appears to be cost-effective when compared with costs of other Hong Kong water supply sources. Taking into account the availability of existing pumping and pipeline facilities, the River Indus appears to be the most favorable source of river water for reclamation. A full evaluation of the cost-effectiveness of reclaiming River Indus flows is warranted. Such an analysis would include a hydrologic evaluation of flows available throughout the year, determination of reclaimed water quality requirements specific to the project, determination of year-round treatment requirements, and development of detailed cost estimates for the project. Reclamation of wastewater also appears to be cost-effective when compared with costs of other Hong Kong water supply sources, and that modifications to planned conventional wastewater treatment facilities may be cost-effective in comparison to treatment by separate reclaimed water facilities. A detailed investigation is warranted of the capabilities of planned conventional wastewater treatment facilities for achieving nutrient removal. In addition, water quality requirements for reclaimed water should be developed and cost estimates prepared for specific projects for reclamation of wastewaters.

While it is unlikely that wastewater reclamation will produce extensive potable supplies for Hong Kong in the near future, reuse of suitably treated effluent for landscape irrigation, flushing and evaporative cooling in new towns of up to 1/2 million population is being actively considered. The results of the AWT pilot plant program will provide valuable information on the feasibility of those applications of reclaimed waters. The knowledge obtained through the test program will also be extremely useful for any future work in environmental control of large bodies of water which might be expected to receive a much higher pollutant and nutrient loading as a consequence of development of new population centers to accommodate the ever-expanding population and the associated industrial activities of Hong Kong.

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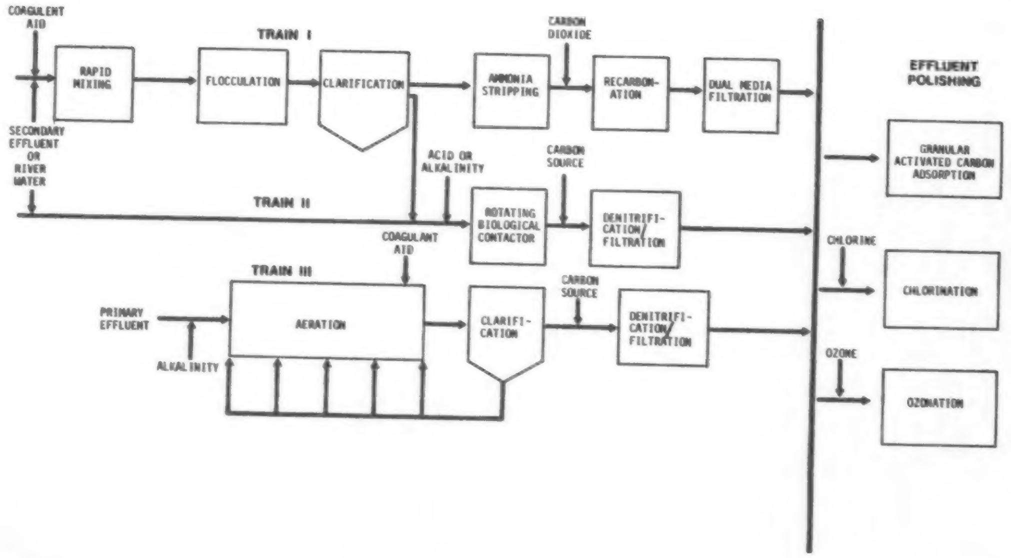
COAGULENT AID
TRAIN I
RAPID MIXING
FLOCCULATION
CLARIFICATION
AMMONIA STRIPPING
CARBON DIOXIDE
RECARBON-ATION
DUAL MEDIA FILTRATION
SECONDARY EFFLUENT OR RIVER WATER
ACID OR ALKALINITY
CARBON SOURCE
TRAIN II
ROTATING BIOLOGICAL CONTACTOR
DENITRIFI-CATION/ FILTRATION
COAGULANT AID
TRAIN III
PRIMARY EFFLUENT
ALKALINITY
AERATION
CLARIFI-CATION
CARBON SOURCE
DENITRIFI-CATION/ FILTRATION
EFFLUENT POLISHING
GRANULAR ACTIVATED CARBON ADSORPTION
CHLORINE
CHLORINATION
OZONE
OZONATION

Figure 1 HONG KONG AWT PILOT PLANT PROCESS SCHEMATIC

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TABLE 1. SOURCE WATERS QUALITY SUMMARY

Constituent	Concentration Stream Water	 Primary Effluent	 Secondary Effluent
BOD, mg/l	50	244	16
COD, mg/l	124	366	110
Suspended Solids, mg/l	25	127	21
Colour	75	-	32
pH	7.0	6.9	6.8
Turbidity, TU	45	-	11
Specific Conductance, µmho/cm	570	-	540
Ammonia Nitrogen, mg/l	26	48	13
Nitrate Nitrogen, mg/l	0.6	< 0.1	7.0
Organic Nitrogen, mg/l	1.7	1.9	1.3
Total Phosphate, mg/l	22	19.0	12.0

TABLE 2. AWT PILOT PLANT PARAMETRIC TEST PROGRAM SUMMARY

Process	Key Treatment Goal	Test Parameters
Train I		
Rapid Mixing, Flocculation Clarification	Suspended solids and phosphorus removal; effluent pH during lime addition	Coagulant dose; hydraulic loading; mixing energy
Ammonia Stripping	Ammonia-nitrogen removal	Hydraulic loading; air to water loading; influent pH; temperature
Recarbonation	pH reduction	CO_2 dose
Filtration	Suspended solids and turbidity removal	Hydraulic loading; influent suspended
Train II		
Rotating Biological Contactor	Nitrification	Hydraulic loading; BOD_5 or TDC loading; ammonia-nitrogen loading
Denitrifying Filters	Turbidity and suspended solids removal; denitrification	Hydraulic loading; carbon source dose; influent suspended solids
Train III		
Activated Sludge System	BOD_5, suspended solids, and phosphorus removal; nitrification	F/M ratio; sludge residence time; coagulant dose, hydraulic loading
Denitrifying Filters	Turbidity and suspended solids removal; denitrification	Hydraulic loading; carbon source dose; influent suspended solids
Effluent Polishing		
Activated Carbon Adsorption	Residual organics removal	Hydraulic loading; contact time; organics loading
Chlorination	Bacteria and virus removal	Chlorine dose; contact time
Ozonation	Bacteria and virus removal	Ozone dose; contact time

TABLE 3. SUMMARY OF COST ESTIMATES FOR FULL-SCALE RECLAMATION OF SECONDARY EFFLUENT IN HONG KONG [a]

Reclaimed Water Quality Level	Total Unit Cost (HK$/1,000 Igal) Physical-Chemical Treatment 10 migd	25 migd	50 migd	Biological Treatment 10 migd	25 migd	50 migd
Level 1	2.63	1.96	1.60	3.50	2.91	2.47
Level 2	3.77	3.02	2.51	4.60	3.95	3.35
Level 3	3.99	3.22	2.68	NA [b]	NA	NA

[a] Mid-1980 costs.

[b] Not applicable. Biological treatment not considered suitable.

TABLE 4. SUMMARY OF COST ESTIMATES FOR FULL-SCALE RECLAMATION OF HONG KONG RIVER WATER BY PHYSICAL-CHEMICAL TREATMENT [a]

Reclaimed Water Quality Level [b]	Total Unit Cost of Treated Water (HK$1,000 Igal) 10 migd	25 migd	50 migd
Level 1	3.33	2.71	2.24
Level 2	3.99	3.22	2.68

[a] Mid-1980 costs.

[b] Treatment to Level 3 quality is not considered technically viable due to the variations in source water quality.

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DEVELOPMENT OF COMPACT WASTE WATER TREATMENT PLANTS FOR NON-POTABLE WATER RE-USE SYSTEM

Hidenori Aya
Associate Professor
Department of Technology
University of Tokyo
7-13, Hongo, Bunkyo-ku, Tokyo 113

Gennosuke Inoue
Deputy General Manager
Department of Water Re-Use Technology
Water Re-Use Promotion Center [WRPC]
2-3-4, Akasaka, Minato-ku, Tokyo 107

Toshiyuki Okabe
Engineer
Department of Water Re-Use Technology
WRPC

Yoshio Murayama
Managing Director
WRPC

ABSTRACT

An individual water re-use system has some advantages compared to a regional water re-use system. They are readiness of construction, decrease in sewage discharge and saving of energy.

Disadvantages are its high cost and occupation of some building space which otherwise could be used for other purpose. Particulary, laws and regulations on buildings in city planning obstruct the introduction of the system by building owners.

Water Re-Use promotion Center has carried out the technological development on compact and less expensive waste water treatment plants for a building water re-use system since 1977, in cooperation with several local governments.

Objectives of this project are as follows:

(1) Development of waste water treatment technologies which can be adapted for wide fluctuating load of building drainage.

(2) Development of more compact waste water treatment plants which can be constructed in limited space of a building.

(3) Promotion of labor-saving device on operation and maintenance as much as possible.

For these purposes, experiments on the following processes have been conducted in Osaka City:

(A) Biological contact oxidation [submerged bed] → Biological filtration

(B) Trickling filtration → Activated carbon filtration

(C) Biological contact oxidation [rotating drum] → Sand filtration

(D) Activated sludge treatment → Ultrafiltration

(E) Moving bed sand filtration → Biological contact oxidation [submerged bed]

(F) Coagulation/sedimentation → Sand filtration → Reverse osmosis (RO)

(G) RO with ball cleaning

Raw water was building drainage excluding night-soil. Experiments were carried out during two or three years for each process.

Reclaimed water by (D) and (E) processes were supplied to flushing toilets and corrosion test equipments.

The conclusions are as follows:

(1) Fluctuation of raw water quality for (A), (B) and (C) processes was pH 5.3∿5.8, SS 100∿200 mg/l, BOD 140∿200 mg/l and COD 50∿100 mg/l.

That for (D) and (E) processes was pH 4.8∿6.5, SS 80∿460 mg/l, BOD 200∿1,000 mg/l and COD 100∿365 mg/l.

That for (F) and (G) processes was pH 4.8∿7.0, SS 30∿100 mg/l, BOD 100∿560 mg/l and COD 60∿140 mg/l.

(2) If equalizing tank were provided, there is no need of the second treatment for the cases of (A), (B) and (C). Water quality from the submerged bed and the trickling filter were less than 10 mg/l for SS, BOD and COD, and less than 15 mg/l for SS, BOD and COD in the case of the rotating drum.

(3) Water quality from the case (D) was less than 5 mg/l for SS and BOD, and less than 10 mg/l for COD.

(4) Water quality from the case (E) was SS 5 mg/l, BOD 10 mg/l and COD 15 mg/l generally.

(5) (F) and (G) processes produced the water with the quality of SS less than 5 mg/l, BOD ca. 20 mg/l and COD less than 10 mg/l. TDS was removed by 80~90%.

(6) Estimated treatment costs of the processes are ¥170~400/m^3 with a plant capacity of 100 m^3/d.

(7) Required area for the construction of a plant with a capacity of 100 m^3/d varied from 40 to 70 m^2 according to the process.

INTRODUCTION

Recently, demand for living water has increased annually in the urban areas of Japan. Particularly, water consumption for living use per capita has exceeded 500 l/d in Tokyo, Osaka and their neighboring areas. According to the report on the survey of living water usage in Tokyo Metropolitan area by the National Land Agency, Japan, 57% of the total living water consumption is used in homes for washing, drinking and eating, bathing, house cleaning and other uses which need clean water, 6% is used for toilet flushing, sprinkling, car washing and other uses, and remaining 37% is used for city activities in schools, hospitals, pools and other places as shown Table 1. In Table 1, "others" in city activities' use includes water consumption in office buildings, stations, airports, department stores, restaurants, etc., and its demand has been increasing along with the concentration of population on the metropolitan area.

Therefore, WRPC began technological development of waste water treatment plants for non-potable water re-use system in a building since 1977, as one of the measures to cope with the water shortage. Objectives of this project are as follows.

(1) Development of waste water treatment technologies which can be adapted for wide fluctuating load of building drainage.

(2) Development of more compact and less expensive waste water treatment plants which can be constructed in limited space of a building.

(3) Promotion of labor-saving device on operation and maintenance as much as possible.

Table 1 Usage of living water in Tokyo Metropolitan area

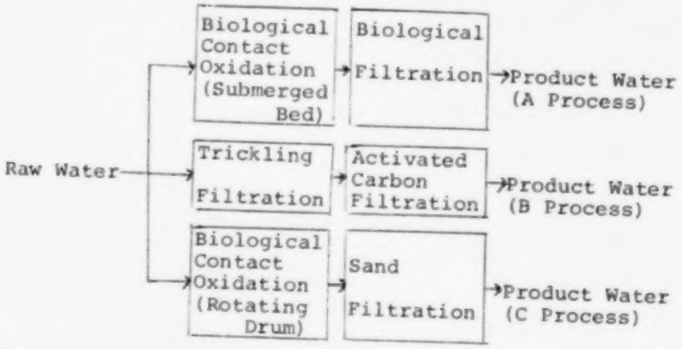
Usage	%
Domestic Use	(63.0)
Washing	19.7
Drinking and eating	13.5
Bathing	8.8
House cleaning	5.1
Toilet flushing	4.8
Sprinkling	0.5
Car washing	0.2
Others	10.4
City Activities' Use	(37.0)
Schools	4.4
Hospitals	2.8
Pools	2.5
Others	27.3

EXPERIMENTAL

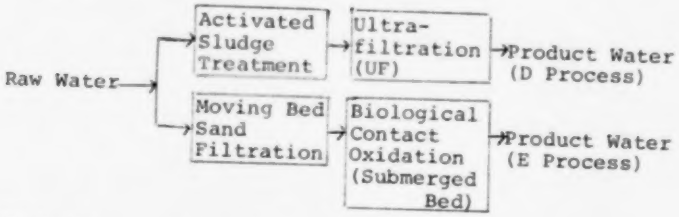
Experimental Site and Process

The experiments on 7 processes were carried out at 3 buildings in Osaka city, namely at the head office building of Nankai Electric Railway Co. (Nankai Building), the building of the Waterworks Bureau, Osaka Metropolitan Government (Waterworks Building) and the Senba Center Building.

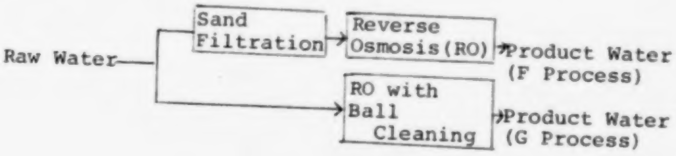
Nankai Building


Raw Water
Biological Contact Oxidation (Submerged Bed)
Biological Filtration
Product Water (A Process)
Trickling Filtration
Activated Carbon Filtration
Product Water (B Process)
Biological Contact Oxidation (Rotating Drum)
Sand Filtration
Product Water (C Process)

Waterworks Building


Raw Water
Activated Sludge Treatment
Ultra-filtration (UF)
Product Water (D Process)
Moving Bed Sand Filtration
Biological Contact Oxidation (Submerged Bed)
Product Water (E Process)

Senba Center Building


Raw Water
Sand Filtration
Reverse Osmosis (RO)
Product Water (F Process)
RO with Ball Cleaning
Product Water (G Process)

Flow diagrams of A, B and C processes, D and E processes and F and G processes are shown in Fig. 1, Fig. 2 and Fig. 3 respectively.

Raw Water Quality of Nankai Building

Raw water used to the experiments was the building drainage exluding night-soil. The quality of the raw water was temp. 18∿30°C, pH 5.3∿5.8, SS 100∿200 mg/l, BOD 140∿200 mg/l, COD 50∿100 mg/l, n-hexane extract 6∿87 mg/l, MBAS 1.6∿4.6 mg/l, Cl^- 25∿90 mg/l, hardness 30∿40 mg/l, electric conductivity 235∿300μS/cm, NH_4-N 0.05∿0.63 mg/l and PO_4-P 0.33∿4.20 mg/l.

As the experimental plants were set up in a room adjacent to the boiler room, the raw water temperature was kept rather high even in winter. SS, BOD and COD of the raw water gave higher value in winter.

Experiment on A Process (Contact Oxidation - Biological Filtration)

Outline of The Experiment. The experiments were carried out mainly on wide fluctuating load in 1977 - 1978 FY and on long term continuous operation in 1979 FY. The biological contact oxidation process was designed as double stage treatment, and saddle and honeycomb shaped filler were used alternately.

The biological filtration process was experimented in 1977 - 1978 FY. But it was stopped in 1979 FY, because the treated water from the biological contact oxidation had sufficient quality for re-use.

Quality of The Treated Water. Quality of the treated water from the 1st contact oxidation stage varied according to the fluctuation of the raw water quality, but those of the treated water from the 2nd stage and the biological filtration process were good and stable.
Results of the experiment showed that the contact oxidation process eliminates SS more than 90%, BOD by 93∿98%, COD by 83∿94% and MBAS by 67∿78% from the raw water. And by the following biological filtration process, these elimination ratios were raised further to more than 97% on SS, to 98∿99% on BOD, to 90∿96% on COD and to more than 93% on MBAS.

Experiment on Fluctuating Load. Relations between BOD loading and BOD of the treated water are presented in Fig. 4 and Fig. 5. BOD of the treated water from the 1st stage of the contact oxidation process was 20∿80 mg/l under the condition of loading 0.8∿2.4 kg BOD/m^3·d.

That from the 2nd stage was less than 10 mg/l under the condition of loading 1.0 kg/BOD/m^3·d. After the biological filtration, BOD of the treated water was ca. 4 mg/l under the condition of loading 0.5 kg BOD/m^3·d.

Amount of Sludge Generated. Amount of the sludge generated in the contact oxidation process was 20∿30 g/m^3 raw water. There was no difference due to types of filling material. Amount of the sludge generated in the biological filtration was ca. 4 g/m^3 raw water.

Experiment on B Process (Trickling Filtration - Activated Carbon Filtration)

Outline of The Experiment. The experiments were carried out mainly on wide fluctuating load in 1977 - 1978 FY and on long term continuous operation in 1979 FY. According to the experimental results of 1977 FY, the volume of the filler in trickling filter was reduced to 60% of the beginning, and the filter was divided in 2 parts for double stage treatment. The experiment on activated carbon filtration was carried out in 1977 - 1978 FY using granular AC, but it was stopped in 1979 FY as the treated water from the trickling filter had sufficient quality for re-use.

Quality of The Treated Water. Results of the experiment showed that the trickling filtration process eliminates SS more than 84%, BOD by 91∿96%, COD by 73∿89% and MBAS by 65∿73%. And by the following activated carbon filtration, these elimination ratios were raised further to more than 90% on SS, to 96∿99% on BOD, to 90∿97% on COD and to more than 99% on MBAS.

Experiment on Fluctuating Load. Experimental results showed good performance of the trickling filtration. BOD of the treated water from the trickling filter was 10 mg/l under the condition of feed raw water quality BOD 167 mg/l and raw water feed 5 m^3/d (24 g BOD/m^2·d.). The elimination ratio was 94%.

Amount of Sludge Generated. Amount of the sludge generated in the trickling filtration process was about 20 g/m^3 raw water.

Experiment on C Process (Contact Oxidation - Sand Filtration)

Outline of The Experiment. The experiments in 1977 - 1979 FY were similar to A and B processes. The rotating drum was improved to double stage treatment. Experiment on sand filtration was continued until September 1979.

Quality of The Treated Water. The rotating drum process gave the elimination ratio of 80∿90% on SS, 87∿95% on BOD, 75∿93% on COD and 49∿65% on MBAS. And by the following sand filtration, these elimination ratios were raised further to more than 90% on SS, more than 92% on BOD and 50∿77% on MBAS, but the elimination ratio on COD was similar as before.

Experiment on Fluctuating Load. Experimental results showed the elimination ratio of more than 90% on BOD under the condition of loading ca. 38 g BOD/m^2·d.

Amount of Sludge Generated. Amount of sludge generated in the rotating drum process was about 14 g/m^3raw water.

Raw Water Quality of Waterworks Building

Raw water used to the experiments was the building drainage excluding night-soil. The quality of the raw water was temp. 14.5∿32.5°C, pH 4.8∿6.5, SS 80∿460 mg/l, BOD 200∿1,000 mg/l, COD 100∿365 mg/l, n-hexane extract 7∿47 mg/l, MBAS 3.5∿17.0 mg/l, Cl^- 48∿85 mg/l, hardness 45∿79 mg/l, electric conductivity 330∿460 μS/cm and NH_4-N 0.4∿2.5 mg/l. As the experimental plants were set up outdoor, temperature of the raw water fluctuated widely.

Experiment on D Process (Activated Sludge - UF)

Outline of The Experiment. The experiments in 1977 - 1979 FY were similar to the former processes.

Quality of The Treated Water. By this process, the treated water with good and stable quality was obtained. The elimination ratios were more than 98% on BOD, more than 88% on COD and more than 88% on MBAS. SS was always less than 5 mg/l by the UF.

Experiment on Fluctuating Load. BOD of the treated water from the activated sludge process was less than 4.1 mg/l under the condition of loading 0.6∿2.8 kg BOD/m^3·d.

Amount of Sludge Generated. Amount of sludge generated in the activated sludge process was 8.7 g/m^3 raw water.

UF. UF was operated with the average pressure of 0.38 kg/cm^2. Total operating time was about 13,000 hrs. The cleaning of the membrane was done by backwashing of 5∿10 minutes every day and by the chemical cleaning of once every 2∿3 months. But the flux decreased by 64% during the 13,000 hrs. operation.

Experiment on E Process (Moving Bed Sand Filtration - Contract Oxidation)

Outline of The Experiment. Experiment on fluctuating load was carried out in 1977 - 1978 FY. In 1979 FY, the moving bed sand filtration and the contact oxidation were operated separately.

In the case of the moving bed sand filter, coagulants (aluminium sulphate and polyelectrolytes) were added in the feed pipe to the filter.

Quality of The Treated Water. Experimental results in 1977 - 1978 FY showed the elimination ratios of more than 90% on SS, 50∿70% on BOD, 55∿63% on COD and 80% on MBAS in the case of sand filtration. And by the following contact oxidation, these elimination ratios were raised further to more than 94% on SS, 95% on BOD, 85∿90% on COD and 96% on MBAS. On the experiments carried out in 1979 FY, the sand filtration process showed the elimination ratios of more than 90% on SS, 43∿60% on BOD, 38∿62% on COD and 70% on MBAS. On the other hand, the elimination ratios by the contact oxidation process were more than 90% on SS, more than 97% on BOD, 73∿90% on COD and 90% on MBAS. Pre-aeration in the raw water tank was effective to remove BOD by ca. 50%.

Experiment on Fluctuating Load. The moving bed sand filter could treat the raw water of less than 1 m^3/hr. Quality of the filtrate was good if SS of the raw water is less than 200 mg/l, and recovery ratio was about 95%. The contact oxidation process showed the elimination ratio of more than 90% on BOD, in case of loading 2.0 kg BOD/m^3.

Amount of Sludge Generated. Conversion ratio of BOD to sludge in the contact oxidation process was 9.0∿16.4%, when operated in series with the moving bed sand filtration.

Raw Water Quality of Senba Center Building

Raw water used to the experiments was the building drainage excluding night-soil. The quality of the raw water was temp. 17.0∿33.5°C, pH 4.8∿7.0, SS 30∿100 mg/l, BOD 100∿560 mg/l, COD 60∿140 mg/l, n-hexane extract 9∿37 mg/l, MBAS 3.5∿12.0 mg/l, Cl^- 50∿84 mg/l, hardness 42∿98 mg/l, electric conductivity 260∿440 μS/cm, T-N 5.1∿9.8 mg/l and PO_4-P 0.01∿1.11 mg/l.

Experiment on F Process (Coagulation - Sand Filtration - RO)

Outline of The Experiment. Tublar type RO modules of high salt rejection (97∿98%) and low salt rejection (65∿75%) were employed in this experiment. Coagulation and sand filtration were adopted as pretreatment system. Cleaning of RO membrane was done mainly by chemical cleaning.

Quality of The Treated Water. High salt rejection modules showed the elimination ratios of 95% on BOD, 94% on COD and 99% on MBAS. Those of low salt rejection modules were 85% on BOD, 88% on COD and 91% on MBAS. SS of the treated water were less than 5 mg/l in both cases. Rejection ratios on evaporation residue were 90% by high rejection modules and 65% by low rejection modules.

Salt Rejection. Salt rejection of both types of modules were unstable at the beginning of operation, but stabilized after 150 hrs. The salt rejections were 95.8% by high salt rejection modules and 69.8% by low salt rejection modules respectively.

Permeate. M-value of high salt rejection membrane was 0.025 and that of low salt rejection membrane was 0.035.

Experiment on G Process (RO with Ball Cleaning)

Quality of The Treated Water. Tublar type modules of salt rejection 95% were employed. Ball cleaning was done once every 30 minutes, and chemical cleaning was done once every 100 hrs. The elimination ratios were 90% on BOD, 93% on COD and 97% on MBAS. SS of the treated water was always kept less than 5 mg/l.

Salt Rejection. The salt rejection of the moduels showed the increasing tendency with lapse of operation time and was always kept more than 93%.

Permeate. M-value of this modules was 0.036.

ESTIMATION OF CONSTRUCTION COST, TREATMENT COST AND REQUIRED AREA

On the basis of the above-mentioned experimental results, construction cost, treatment cost and required area for a plant construction have been estimated. Design conditions are as follows.

Raw Water Quality and Product Water Quality.

Raw water is building drainage excluding night-soil. Raw water and product water were assumed to have the quality shown in Table 2.

Table 2 Quality of Raw and Product Water

	Raw Water	Product Water
Temperature (°C)	15 ∿ 30	15 ∿ 30
pH	5.5 ∿ 6.5	6.0 ∿ 7.5
Turbidity (degree)	100	10>
Color (degree)	60	20>
SS (mg/l)	100 ∿ 150	10>
BOD (mg/l)	200 ∿ 300	20>
COD (mg/l)	ca. 150	20>
MBAS (mg/l)	ca. 10	2*>

* In some cases 2<

Capacity and Process

Estimation were carried out on the following 5 processes with a capacity of 30, 50, 100, 300 and 500 m^3/d.

Process H

Raw water → Contact oxidation → Sand filtration → Chlorination → Product water

Process I

Raw water → Trickling filtration → Sand filtration → Chlorination → Product water

Process J

Raw water → Sand filtration with pre-coagulation
Contact oxidation → Chlorination → Product water

Process K

Raw water → Activated sludge treatment → UF →
Chlorination → Product water

Process M

Raw water → Chlorination → Sand filtration with
pre-coagulation → RO → Chlorination → Product water

Construction Cost and Treatment Cost

Construction cost and treatment cost were estimated as of Feb. 1979.
Treatment cost includes fluctuating expense, depreciation (including the rate of interest) and maintenance expense.
Estimated value of construction includes installation cost, appurtenant work cost and expense for test working in addition to manufacturing cost of a plant.
Estimated value excludes the followings.

(1) Foundation work

(2) Accepting works of raw water and utilities intake from outside.

(3) Facilities for product water service system.

(4) Purchasing expense or rental value of site or space.

(5) Electric power and water for construction work.

(6) Cost for sludge treatment or disposal.

(7) Personnel expenses

(8) Expense for water analysis

On the estimation, following unit costs were applied.

Electric power	¥11 /kWhr
Coagulant	¥13 /kg
Chlorine	¥56 /kg

Maintenance cost was assumed to 0.5% of the construction cost.
Depreciation terms were assumed 15 years for civil engineering and construction works, and 7 years for machinery.

$$\text{Depreciation cost} = \frac{(\alpha + \beta)(1 + K)\,M}{365} \quad (¥/d)$$

α : Rate of interest (= 0.071)

β : Depreciation rate by fixed amount method (0.066 for civil engineering and construction works, and 0.142 for machinery)

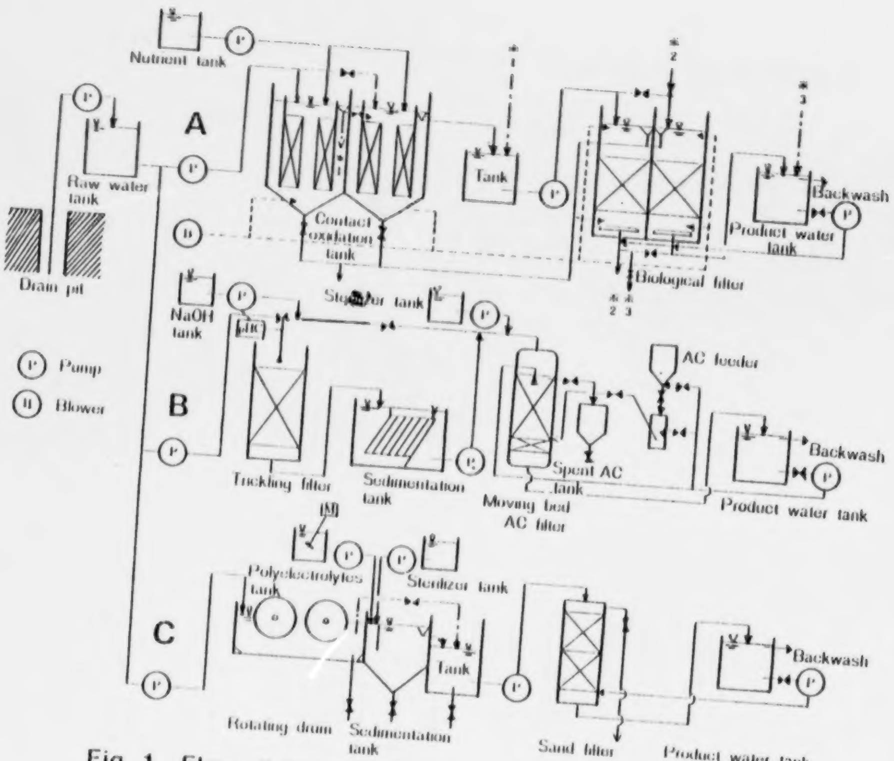
K : Rate of construction interest (= α x 0.4 x 1y. = 0.0284)

M : Construction cost

Construction cost, treatment cost and required area for a plant installation are shown in Fig. 6, Fig. 7 and Fig. 8 respectively.

CONCLUSION

H, I, J, K and M processes can be used for non-portable re-use system in a building. Treatment costs of H, I and J processes are less expensive compared to K and M processes. But water quality of K and M processes are better than those of H, I and J processes.



Nutrient tank
A
B
C
Raw water tank
Drain pit
Pump
Blower
Contact oxidation tank
Tank
Biological filter
Product water tank
Backwash
NaOH tank
Sterilizer tank
Trickling filter
Sedimentation tank
Moving bed AC filter
Spent AC tank
AC feeder
Product water tank
Backwash
Polyelectrolytes tank
Sterilizer tank
Rotating drum
Sedimentation tank
Tank
Sand filter
Product water tank
Backwash

Fig. 1, Flow diagrams of A, B and C processes

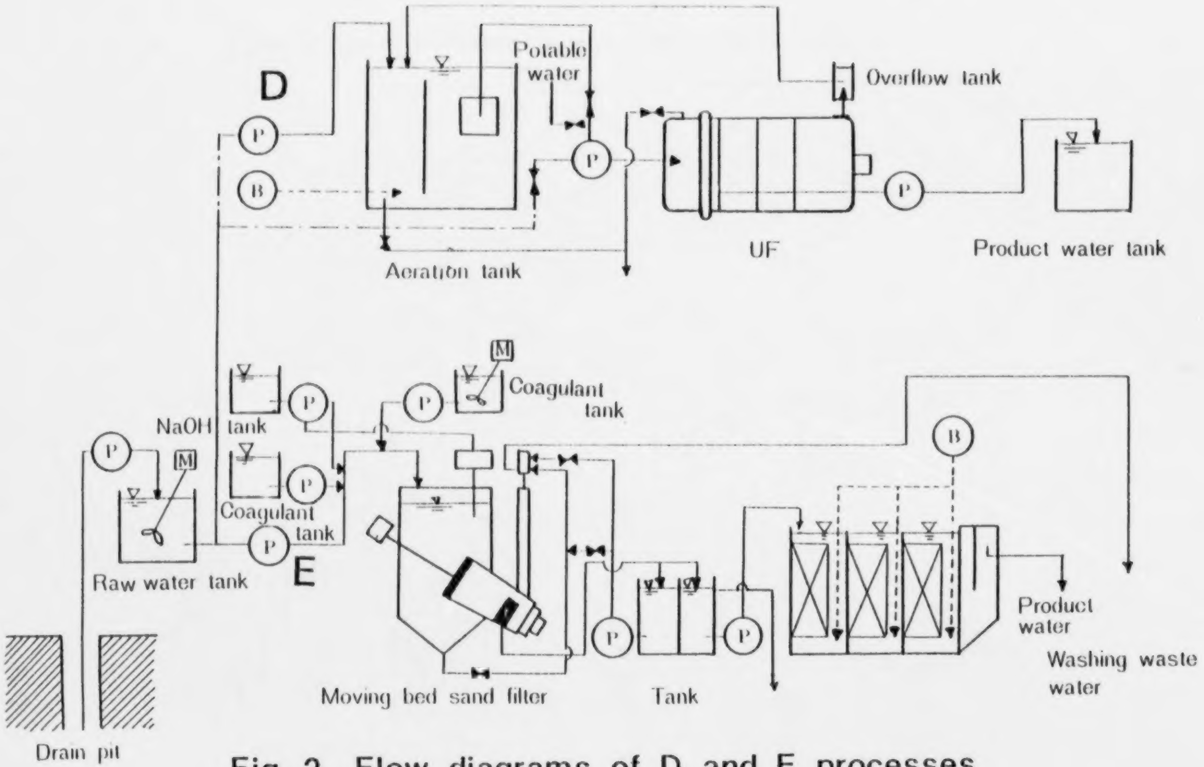

D
P
B
Potable water
Overflow tank
P
P
UF
Product water tank
Aeration tank
NaOH tank
Coagulant tank
P
P
Coagulant tank
M
P
P
M
Raw water tank
E
P
B
Moving bed sand filter
P
Tank
P
Product water
Washing waste water
Drain pit

Fig. 2, Flow diagrams of D and E processes

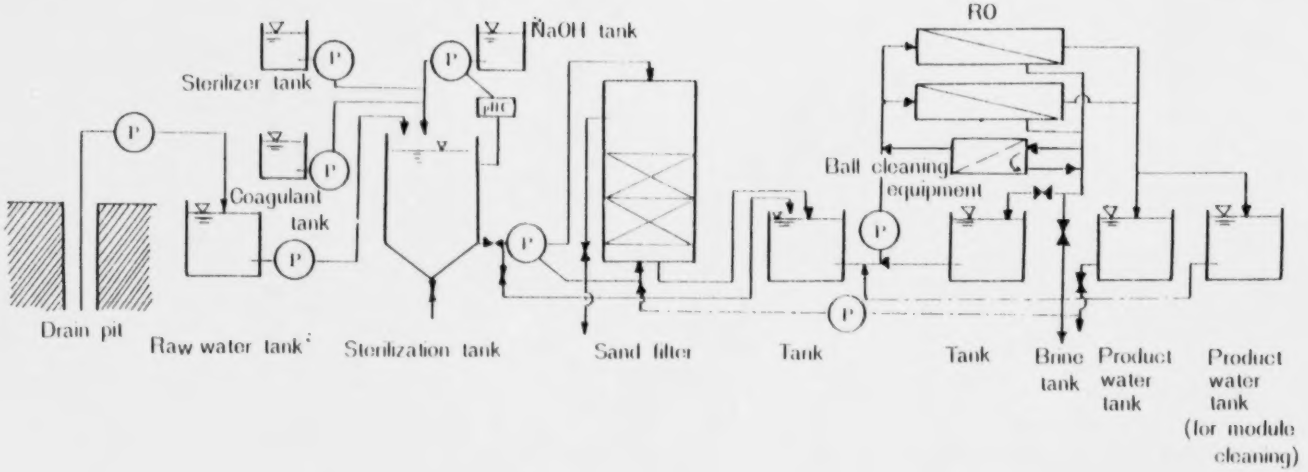

RO
Sterilizer tank
NaOH tank
P
pHC
Ball cleaning equipment
Coagulant tank
Drain pit
Raw water tank
Sterilization tank
Sand filter
Tank
Tank
Brine tank
Product water tank
Product water tank (for module cleaning)

Fig. 3, Flow diagrams of F and G processes

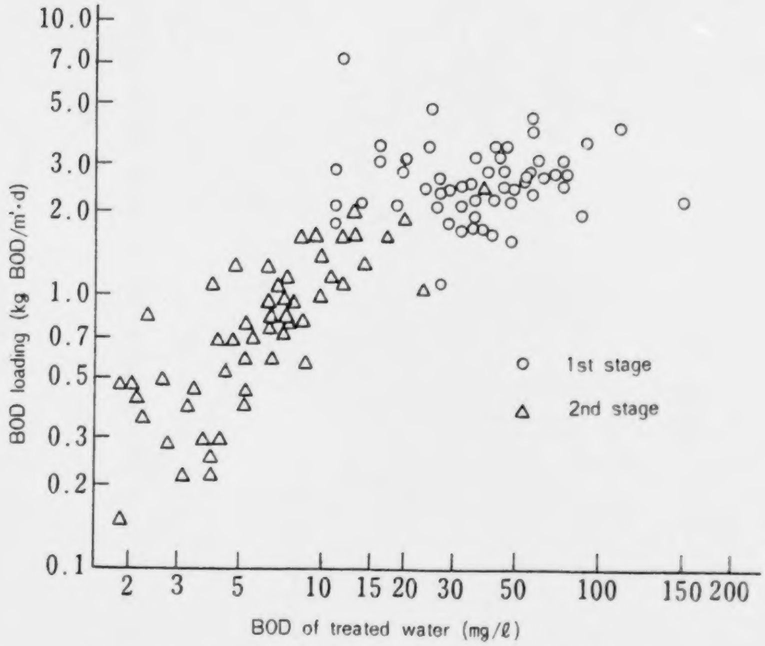


Fig. 4, Relation between BOD of treatedwater and BOD loading (Contact oxidation)

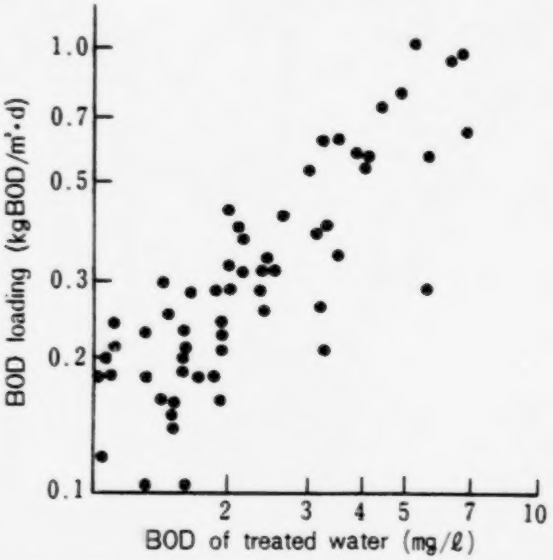


Fig. 5, Relation between BOD of treatedwater and BOD loading (Biological filtration)

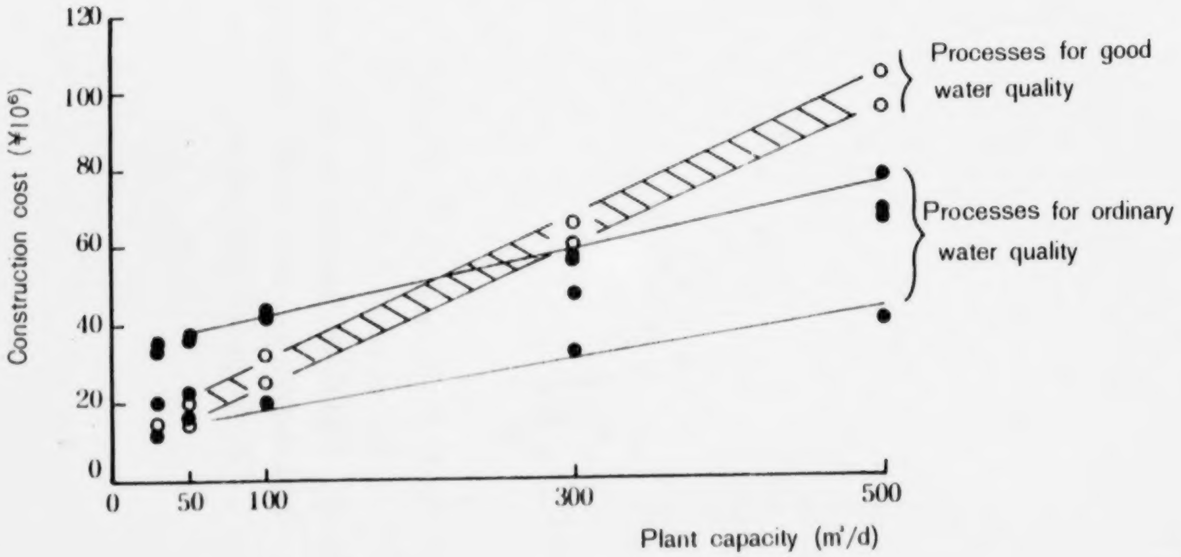
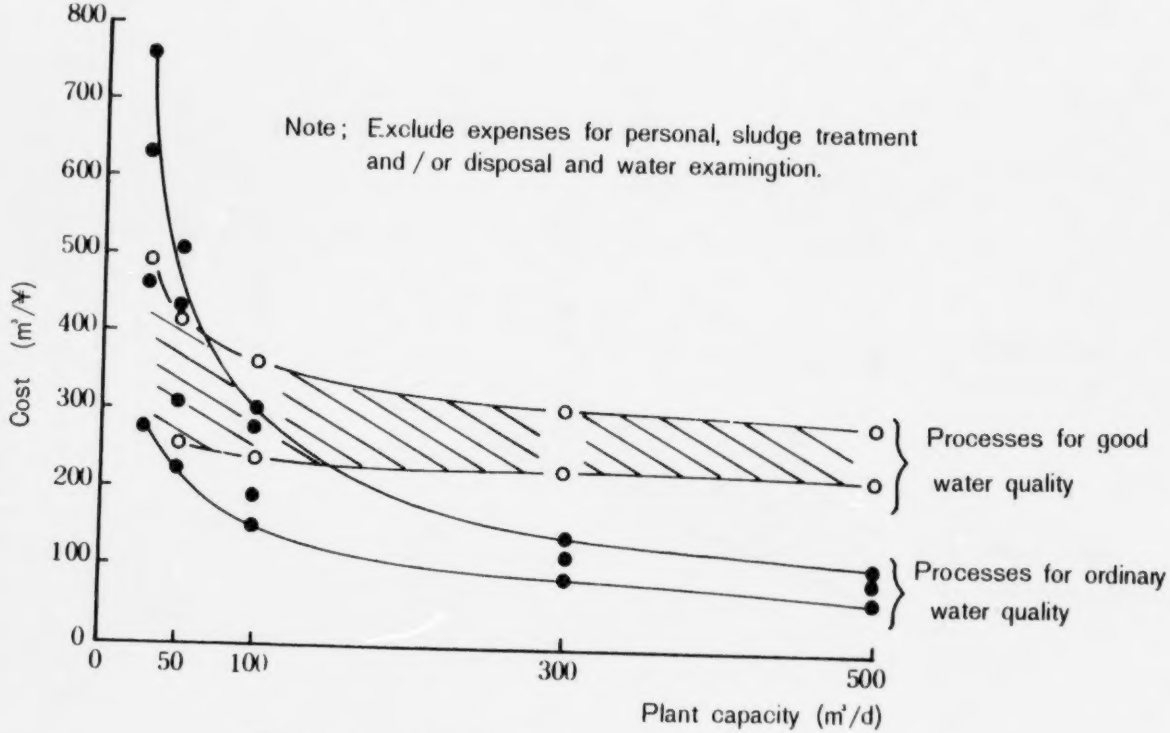


Fig. 6, Construction cost



Note; Exclude expenses for personal, sludge treatment and / or disposal and water examingtion.

Fig. 7, Treatment cost

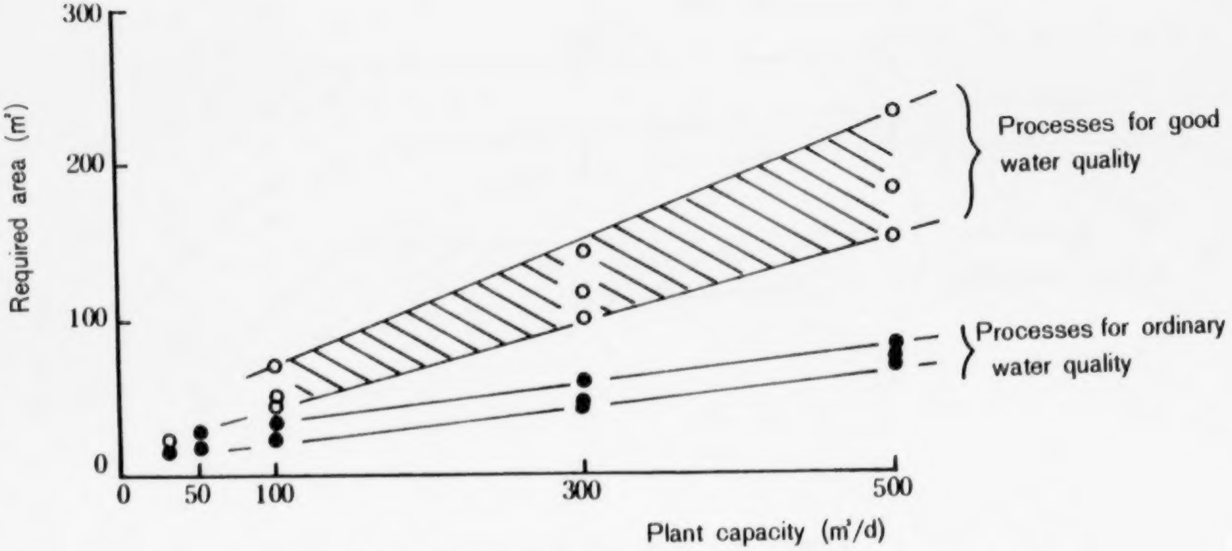


Fig. 8, Reguired area

PB82-223413

A CASE OF RAW WASTEWATER IRRIGATION IN SICILY

Salvatore Indelicato
Full Professor

Orazio Li Destri
Associate Professor

Vincenzo Tamburino
Researcher

Istituto di Idraulica Agraria - Università di Catania
V. Valdisavoia 5 - 95123 Catania Italia

INTRODUCTION

The use of wastewater for irrigation has been a subject of increasing attention in the current years. Many questions have been raised with regard to long-term changes in physical and chemical properties of soil which may affect the plant growth (1,2). An orange orchard, irrigated with raw municipal wastewater for more than 50 years, was selected as a case study in order to assess the long-term responses of the soil-plant ecosystem to sewage application. The case study area is located in Italy near Lentini, in the Sicily Island. In this region the use of untreated or partially treated municipal wastewater for irrigation is a somewhat common practice.

In figure 1 some sites of Eastern Sicily where wastewater is reused for irrigation are pointed out. The data refer to an investigation restricted to only 1/3 of the total amount of sites. The plots irrigated with wastewater are generally small (a few hectares or even less). The most widespread cultures are citrus and vegetables.

Some questions have been raised concerning the high boron concentration in Italian municipal wastewater which may have toxicity effects on sensitive crops such as citrus. This is why in this case-study attention has been given to the effects of absorption of boron by orange-trees.

The objectives of this investigation are:
- to describe a case of "de facto reuse" of untreated municipal wastewater which can be considered typical for Sicily;
- to evaluate some long-term effects of wastewater irrigation on chemical soil properties (i.e. phosphorus and potassium content);

- to evaluate the absorption of wastewater boron by orange trees.

CASE DESCRIPTION

Background information

The citrus orchard considered is near Lentini, a little town of 32,000 inhabitants in the South-East of Sicily. It is built on small hills at an elevation of about 70 m, about 10 Km apart from the Jonio Sea. The population is mostly devoted to agriculture and related activities. Lentini is crossed by three streams covered with vaults. In the last century, in these streams there was only clean water. Today a big part of the town's sewer outlets flows into these streams where in summertime there is, for this reason, only wastewater. The sewerage system is incomplete and is not connected to the treatment plant built in 1975 and never used. In summertime Lentini wastewater is partially taken from the streams to be used by the farmers to irrigate citrus orchards and partially infiltrates into the soil. During the rainy season, sewerage diluted with clean water flows into S. Leonardo River which in turn flows into the Jonio Sea.

The climate is typically Mediterranean with annual precipitation of about 650 mm(average 1921-50) occurring mainly in the October - April period, and a potential evapotranspiration of about 925 mm/per year.

Soil and site characteristics

The soil is sandy loam (67% of sand, 23% of silt), well drained, calcareous (53% of $CaCO_3$). The citrus orchard irrigated with wastewater has an area of about 12 ha; there are orange cultivars Moro, Sanguinello and Ovale. Some plots have been cultivated since 1880 and others since 1930. The farm lays west of the town and south of the Lisso stream ;it is a flat land with a slope of about 2% to the West.

Raw wastewater is taken from the stream and applied by basin irrigation every 20-30 days (4-5 waterings during the irrigation period). Every 3-4 years artificial fertilizer is used at the rate of about 450 Kg/ha of nitrogen, 150 Kg/ha of phosphoric anhydrite and 150 Kg/ha of potash.

The citrus orchard despite the inadequate number of waterings and the limited amount of artificial fertilizer used, is in quite good vegetative conditions. A few symptoms of boron excess represent the exceptions. The boron excess effects have begun near 1975. For this reason, at the end of every irrigation season some of the leaf tips turn yellow and burned. However the productivity does not seem to be reduced.

In the farm there is neither bad smell nor drawbacks of esthetic nature. There is no evidence of health hazards caused by sewage irrigation. The orange fruit is not in direct contact with wastewater while it can get accidentally in contact with the soil during the period of harvesting, which occurs 3-7 months after the last watering.

The water table under the wastewater irrigated farm is within 2-5 m below the land surface. In the farm there are three dug wells near the Lisso Stream.

Wastewater characteristics

The quality of municipal wastewater is considerably variable. Therefore four composite samples have been collected in summertime between 8a.m. and 4p.m. during working-days and then analyzed. The average characteristics of wastewater used for irrigation are the following: ph 7.6, electrical conductivity 1.055 mS/cm, COD 489 ppm, total nitrogen 47 ppm, total phosporus 12 ppm, potassium 18 ppm, calcium 55 ppm, magnesium 22 ppm, sodium 129 ppm, boron 2 ppm, SAR 3.7.

The sewage before being applied to the soil is neither purified nor meaningfully diluted with clean water. The values of electrical conductivity and of SAR, even if they are not very low, can be quite acceptable in relation to the soil characteristics of the farm to be irrigated. On the contrary, the boron concentration seems to be extremely high in relation to the remarkable phytotoxicity of this element.

RESULTS OF THE INVESTIGATION

Soil

In order to analyze the soil, three plots of a total area of 2 ha, cultivated with oranges "Moro" planted in 1930, have been selected. Other three plots in a nearby orange orchard irrigated with well water of good quality (electrical conducivity 0.66 mS/cm, SAR 1.3) have been chosen as a control. In May 1980 before the irrigation season, composite samples of soil were taken at three different depths (0-20, 20-40 and 40-60 cm). Analyses of some parameters have been repeated on samples of soil taken from plots irrigated with wastewater after the end of the irrigation season. The chemical analyses have been done using the methodology proposed by A.O.A.C. (3).

In figure 2 the results of the analyses concerning phosphorus,potassium,nitrogen,organic matter and boron are reported.Three values are indicated for each parameter and soil depth.An increase in the content of total phosphorus and extractable potassium in the wastewater irrigated soil is evident compared to the one irrigated with well water,especially at lower depths.Extractable phosphorus and total potassium seem to increase,eventhough less,at lower depths. Concerning the organic matter and nitrogen contents,no remarkable changes are evident.There are no long-term changes in the concentrations of boron.The boron content in the water saturated extract of soil irrigated with wastewater, shows normal values at the end of the rainy season and higher values at the end of the irrigation period.It is evident that this element tends to accumulate in the soil during the irrigation period to be eventually leached during the rainy season.

In table 1 the average values of the results of all soil analyses are reported.In that table the determination of some elements in the water saturated extract of soil are also inclosed.Clorides,sodium and SAR of the water saturated extract are higher in the wastewater irrigated soil opposed to the well water irrigated one and they tend to increase after the irrigation period.

Plant composition

In Autumn 1980,in three different dates,orange leaf samples have been collected at both wastewater and well water irrigated farms.The sampling has been made following the methodology proposed by Chapman (4).

In figure 3 the results of boron measures taken on leaf samples are reported.The boron content in the leaves of orange trees irrigated with wastewater resulted to be clearly higher(average of about 10 times)than the control.It is also possible to notice some difference between the samples taken in different dates in the farm irrigated with wastewater.

In accordance with the literature data the content of boron in the citrus leaves with mild toxicity symptoms may vary from 250 to 600 ppm,while in the leaves of citrus orchards seriously damaged,the boron content may reach values up to 2400 ppm (5).

Groundwater

In 1980 four samples, taken in different periods from a shallow well located within the wastewater irrigated farm and distant 20 m from the Lisso Stream, were taken and analyzed.

Groundwater characteristics are reported in table 2.Quite high nitrogen concentrations are evident. It has to be taken in consideration that such high concentrations could be related to the heavy nitrogen fertilization that is made in the nearby citrus orchards. Also coliforms bacteria, phosphorus, boron and high concentrations of potassium were found. It is difficult to assess groundwater quality changes attributable to the practice of using raw wastewater for irrigation. In fact, the samples are taken from a well that is exposed to potential pollution and it may accidentally get polluted by loam and organic material coming from outside. Furthermore it is possibile that the wastewater flowing into the Lisso Stream infiltrates into the underground and pollutes the well water.

CONCLUSIONS

The results of this investigation have given some indications concerning the effects of wastewater irrigation on soil and orange plants. Concerning the long-term effects of wastewater irrigation, the investigation has pointed out higher concentrations of total phosphorus and extractable potassium in the wastewater irrigated soil compared to the well water irrigated one. Those increases are evident, eventhough less, refering to extractable phosphorus and total potassium. The deeper penetration of those fertilizer elements gives some advantages when there are arboreous cultures that develop their radical apparatus at lower depths of soil.Concerning the nitrogen and organic matter contents, no important differences between the wastewater irrigated soil and the control soil have come out. On the other hand those differences may be likely put in evidence by analyzing a more superficial layer of soil,a few cm deep (instead of 20 cm).

On the whole, the irrigation with wastewater does not seem to have produced undesiderable long-term effects on the soil.On the contrary a serious problem is the high boron contents found in the wastewater. That element does not seem to have built up in the soil because it is likely to be leached by the winter rain. During the irrigation season it is likely to occur an increase in the total boron content of the soil and in the water saturated extract of soil. That increase produces some toxicity symptoms on the plants. In Autumn the boron concentration in the leaves of the wastewater irrigated citrus orchard was on an average about ten times higher in comparison to the control. In the case-study the noxious effects due to the high boron concentration in the irrigation water have been probably minimized by the irrigation modality (the first watering is late in June) and by the soil characteristics (rather calcareous and well drained). In different conditions the boron injuries to citrus orchards and other sensitive cultures irrigated with municipal wastewater could be more serious.

Boron comes from the use of domestic detergents, in which it is added in the form of sodium perborate, a bleach that yelds hydrogen peroxide. In the last years in Italy, the boron concentration has increased because of the increased use of detergents. Given that boron is not removed by conventional wastewater treatment plants(6)it is necessary to orient the industrial production of detergents to substitute, even partially, other substances such as percarbonates or organic bleaches for perborate, in the same way as it is done in other countries.

ACKNOWLEDGEMENT

The authors wish to acknowledge the technical contribution by ing. C.C.Giuffrida.

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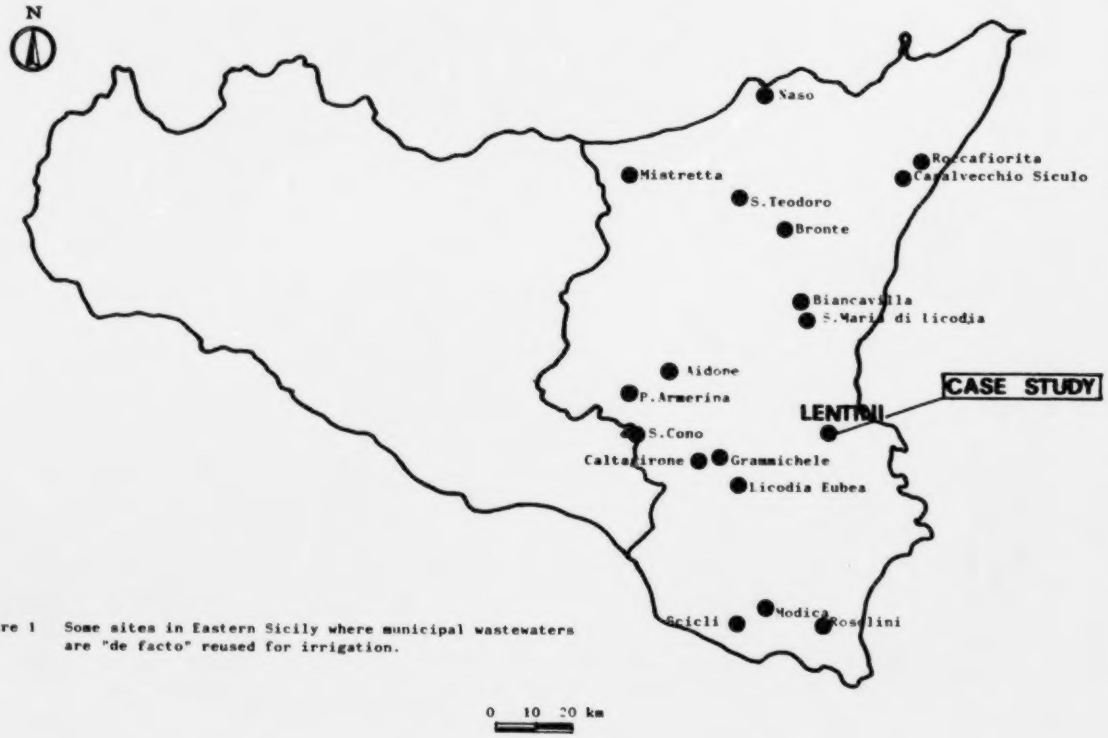
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Figure 1 Some sites in Eastern Sicily where municipal wastewaters are "de facto" reused for irrigation.

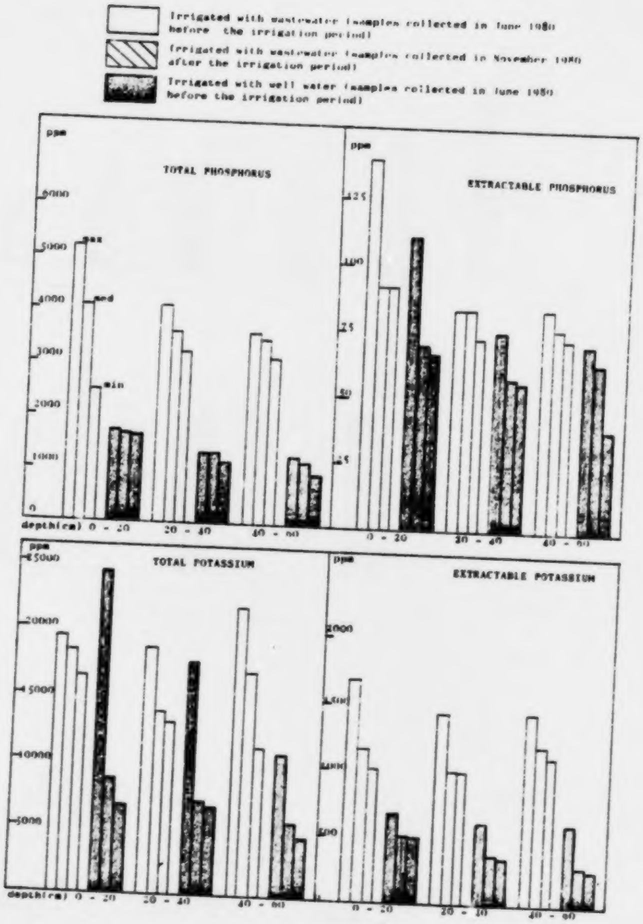


Figure 2 Comparison of several characteristics of wastewater irrigated soils with those of well water irrigated soils (Results are based on dry weight of soil)

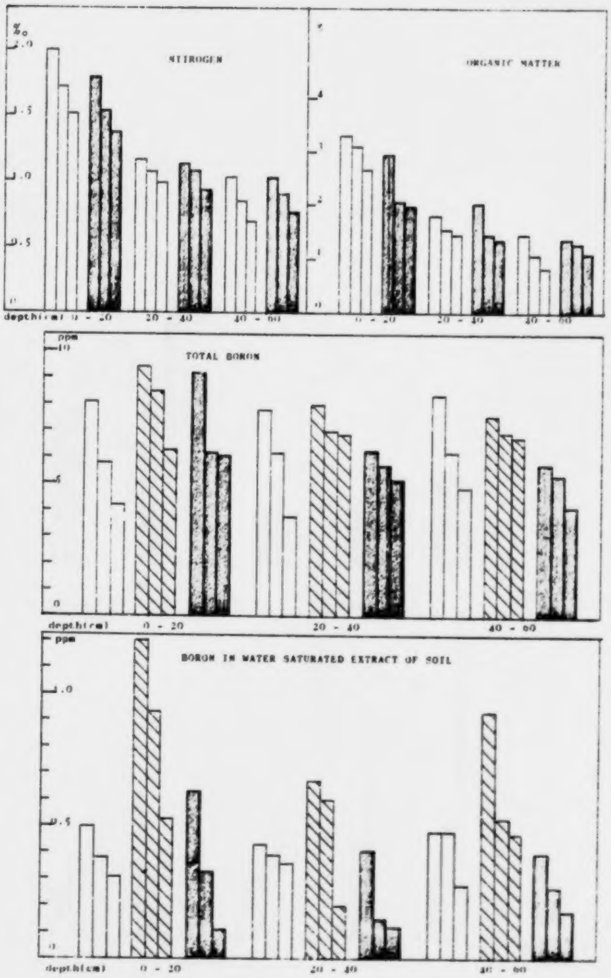


Figure 2 (cont.)

Table 1. Average contents of selected chemical elements in soil irrigated with wastewater and in soil irrigated with well water. (Average values on 3 samples. Results are based on dry weight of soil).

Elements	Soil Depth cm	Irrigated with wastewater June 1980[a]	Irrigated with wastewater Nov. 1980[b]	Irrigated with well water June 1980[a]
Total P ppm	0-20	3935		1700
	20-40	3670		1302
	40-60	3443		1176
Extractable P ppm	0-20	107		83
	20-40	80		64
	40-60	78		58
Total K ppm	0-20	18086		12999
	20-40	15087		10499
	40-60	16606		7030
Extractable K ppm	0-20	1281		567
	20-40	1156		455
	40-60	1260		397
Total N %	0-20	1.73		1.56
	20-40	1.07		1.06
	40-60	0.85		0.89
Organic Matter %o	0-20	3.05		2.38
	20-40	1.66		1.64
	40-60	1.15		1.28
Total B ppm	0-20	6.03	8.07	7.16
	20-40	5.93	7.33	5.76
	40-60	6.53	7.13	5.13
B[c] ppm	0-20	0.40	0.89	0.36
	20-40	0.40	0.49	0.23
	40-60	0.41	0.64	0.28
ph[c]	0-20	7.6	7.4	7.6
	20-40	7.7	7.6	7.6
	40-60	7.8	7.6	7.7
Electrical conductivity[c] mS/cm	0-20	0.91	2.59	1.37
	20-40	0.73	0.78	0.92
	40-60	0.75	0.73	0.73
Cl[c] meq/1	0-20	1.60	4.92	0.74
	20-40	1.09	7.38	0.88
	40-60	1.48	7.53	0.76
Na[c] meq/1	0-20	2.48	7.45	1.51
	20-40	2.51	2.75	1.43
	40-60	2.85	2.60	1.28
Ca[c] meq/1	0-20	2.56	7.32	7.74
	20-40	2.24	2.27	3.81
	40-60	2.40	1.75	3.13
Mg[c] meq/1	0-20	1.75	3.30	2.78
	20-40	1.37	1.73	2.36
	40-60	1.54	2.04	1.97
SAR[c]	0-20	1.51	3.36	0.64
	20-40	1.87	1.93	0.84
	40-60	1.99	7.86	0.80

[a] Samples collected in June 1980 before the irrigation season

[b] Samples collected in November 1980 after the irrigation season

[c] Measured in water saturated extract of soil.

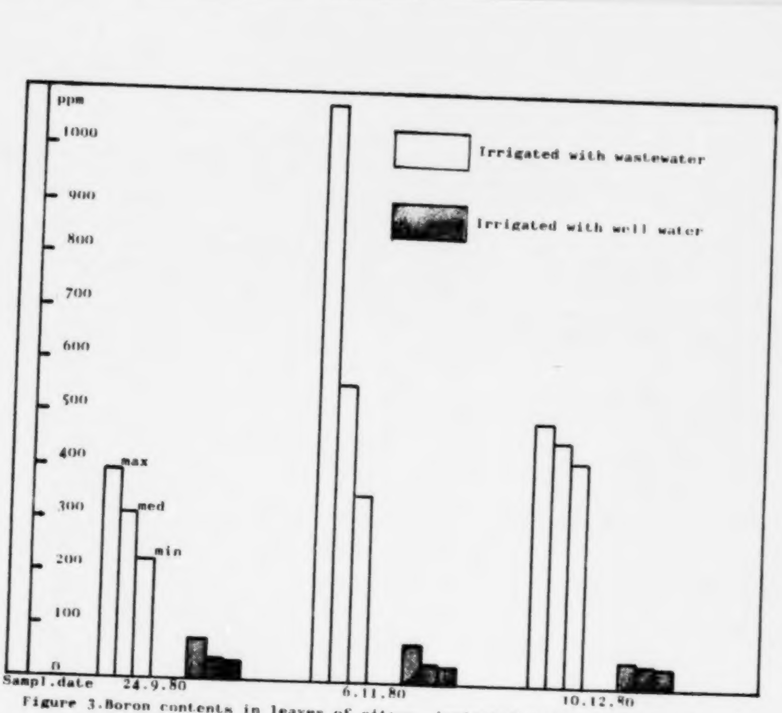
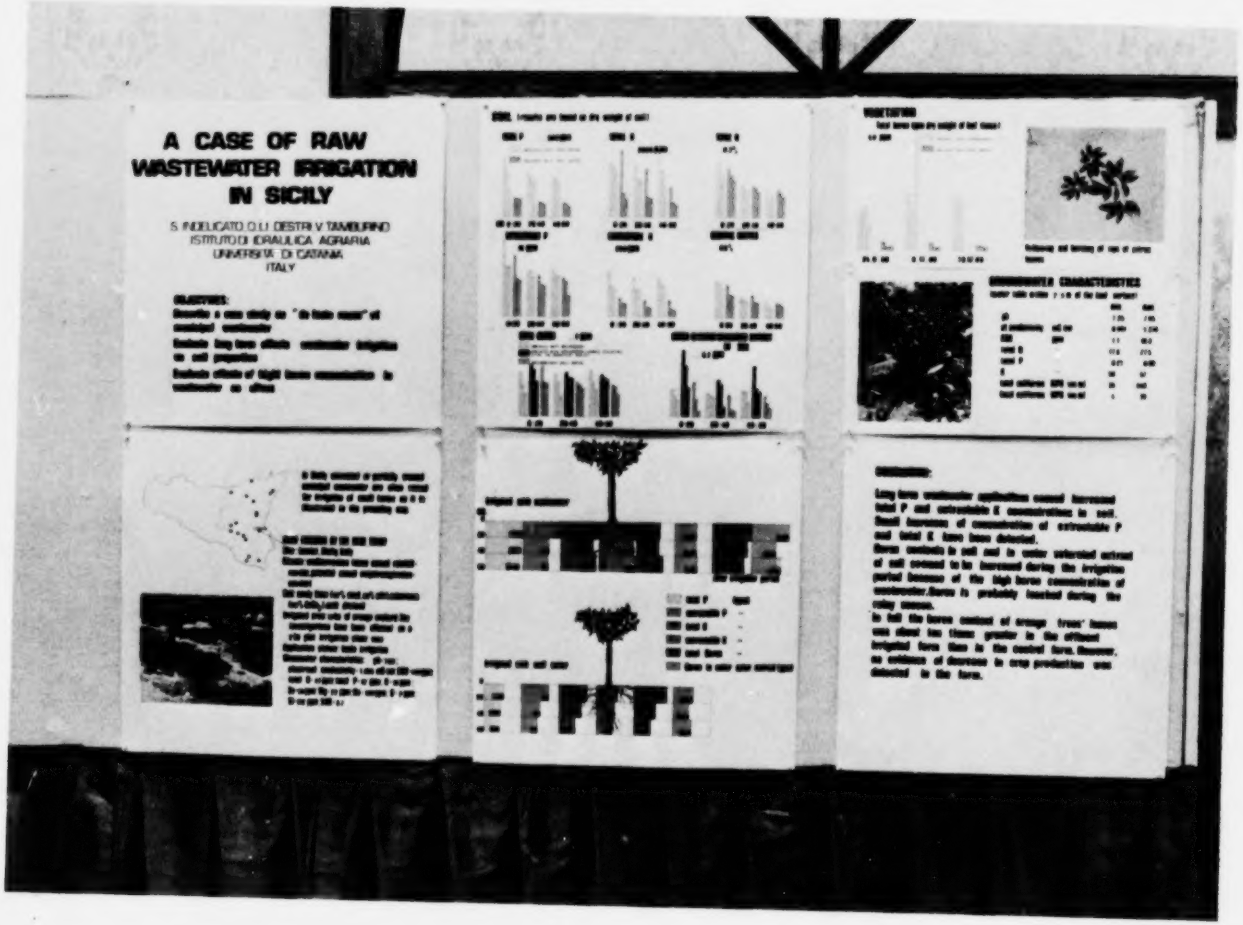


Figure 3.Boron contents in leaves of citrus irrigated with wastewater and with well water(Results are based on dry weight of leaf tissue).

Table 2. Characteristics of groundwater in the sewage irrigated farm

Elements	Date of sampling			
	21.4.80	19.6.80	24.9.80	6.11.80
ph	7.3	7.2	8.0	7.3
Electr.Conductivity mS/cm	1.10	0.99	1.12	1.28
COD ppm	1.1	10.3	8.0	4.2
Total N ppm	17.6	27.4	24.0	24.5
Total P ppm	0.80	0.48	0.27	0.69
K ppm	49.6	54.3	57.4	51.9
Ca ppm	125	121	131	119
Mg ppm	26.0	24.6	32.1	24.3
Na ppm	98	96	103	101
B ppm	0.59	0.02	0.02	0.35
Cl ppm	105	93	90	93
SAR	2	2.1	2.1	2.2
Total Coliforms MPN/100 ml	49	35	540	240
Fecal Coliforms MPN/100 ml	4	23	23	79



A CASE OF RAW
WASTEWATER IRRIGATION
IN SICILY

S. INDELICATO O.I.I. DESTRI V. TAMBURINO
ISTITUTO DI IDRAULICA AGRARIA
UNIVERSITA' DI CATANIA
ITALY

WATER REUSE
SYMPOSIUM II

INDUSTRIAL RECYCLING AND REUSE

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PB82-223421

THE EPA RESEARCH & DEVELOPMENT
PROGRAM IN INDUSTRIAL WASTEWATER RECYCLE/REUSE

Marshall Dick
Senior Engineer
Office of Research & Development
Environmental Protection Agency
Washington, D.C. 20460

INTRODUCTION

The EPA has long been aware of the concept and benefits of wastewater recycle/reuse and has been conducting recycle/reuse activities in several industrial areas for many years. An extensive concerted long range program has recently been initiated by EPA's Office of Environmental Engineering and Technology for the research, development, and application of existing and advanced technologies in industrial wastewater use reduction, reuse and recycle.

Today I would like to define our specific motivation for a recycle/reuse research program and the major benefits of recycle/reuse systems. This will be followed by a discussion of the rationale for selection of specific industrial areas of concentration and a description of our current and ongoing projects. In order to be realistic I will conclude with a discussion of the technological and institutional "barriers" to the acceptance and implementation of recycle/reuse systems by the industrial community.

PROGRAM GOALS

One of the major goals of our research program is the control of water pollutants through attainment of zero discharge of pollutants by 1985, as mandated by the Clean Water Act. Currently, recycle and reuse of water and waste materials is the most viable alternative in support of "zero pollutant discharge". Major benefits of recycle/reuse systems include 1) containment of both conventional and toxic pollutants, 2) reduction of wastewater volume, 3) reduction of intake water, 4) improved treatment efficiency, 5) cost and energy savings, and 6) conservation of water, raw materials and other natural resources.

The Office of Water Resources and Technology of the Department of the Interior also conoducts a very active program in industrial wastewater recycle/reuse. Their main interest is in the conservation of water and other natural resources. The main thrust of the EPA program is to prevent toxic materials from entering our nations waterways and thus we tend to concentrate on the industries where toxic or "priority" pollutants occur. Naturally the two Agency programs are interrelated and there is close cooperation and coordination to insure that the two programs are complimentary rather than duplicative.

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PROGRAM DIRECTION

A great deal of thought was given to the selection of industrial segments as prime candidates for the development and demonstration of recycle/reuse systems. Criteria for the selection included but were not limited to 1) water consumption 2) presence and quantity of toxic pollutants 3) industry growth rates, 4) existing recycle/reuse practices 5) technology transfer, 6) economic and energy considerations 7) project costs 8) conservation considerations and 9) probability of success. A large amount of data was assembled from various sources such as the Bureau of the Census, Dunn and Bradstreet, and internal EPA files to assist in application of these criterria to the selection process.

The industries we have identified for concentrated efforts in the initial stages of our program are 1) petrochemicals, 2) organic chemicals 3) iron and steel manufacturing, 4) textile industry and 5) food processing. These were selected mainly on the basis of high volume of discharge, presence of toxic pollutants, existing practice of recycle technology, and expressed Effluent Guidelines Division interest. We envision a fairly broad spectrum of activities to include such things as feasability studies, technology development, application of foreign technology, pilot plant studies, full scale demonstrations, documentation of existing reuse/recycle systems, and cost benefit studies.

PROJECT DESCRIPTIONS

I would now like to describe some of our ongoing projects to give you the flavor of our program. First a word of orientation as to the organization and location of our industrial program. The industrial wastewater research program is conducted by the Industrial Environmental Research Laboratories (IERL) located in Cincinnati, Ohio and Research Triangle Park, North Carolina with support from the Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma. The Cincinnati Laboratory's effort are concentrated in the following industries: organic chemicals, inorganic chemicals, metal finishing, nonferrous metals, food processing and wood products. The RTP laboratory's efforts are concentrated in the iron and steel, textiles and agricultural chemicals, industries. The Ada laboratory's efforts are concentrated in the petroleum refining and petrochemical industries and combined industrial-municipal waste treatment.

The first project I'd like to describe is in the petrochemicals area. Under a cooperative agreement with the University of Houston and U.S.S. Chemicals Inc. a demonstration of side stream softening to permit maximum recycle is underway at a petrochemical (ethylene, styrene) manufacturing plant in Houston, Texas. In this plant process wastewater is collected and recyled through cooling towers. Application of the new softening system has reduced wastewater discharge by about 90 percent. The particular problems specific to reuse/recycle, being addressed are corrosion considerations, the possible build up of toxics in the softener sludge, and sludge disposal.

In the textile industry we are concentrating on indirect dischargers, that is the plants which discharge to municipal treatment systems. This represents the bulk of the industry. We plan to select typical plants by means of a contract survey and then characterize their wastewaters by chemical composition and treatability. By treatability we mean removal or destruction of pollutants by various technologies. This study will then be followed by a demonstration of a recycle/reuse system at a small textile mill.

One of the potential problems in the application of recycle/reuse systems is the build up of pollutants in the waste streams which must be treated. The Agency has a mobile waste treatment system which consists of a series of vans equipped with pilot scale biological and physical chemical treatment equipment. By use of this system we will conduct studies of the effect of various combinations of treatment technologies on actual steel plant waste streams where high recycle rates are being used. Another way to increase the extent of recycle/reuse is to reduce process blowdowns. A project has been initiated to demonstrate, at operating steel plant sites, that blowdown volumes can be reduced to minimum levels through careful control of water inputs and water chemistry.

In the food industry we are assisting in the demonstration of the application of foreigh technology to a potato starch plant in Maine. In this project a process modification will be used to achieve a drastic reduction in fresh water connsumption and at the same time yield a by-product which has potential as an animal feed component.

We are sponsoring a variety of activities in the organic chemicals area. These include 1) pilot scale evaluation of a Swedish Ion Exchange Technology for the treatment of organic dye wastewaters 2) an environmental assessment of an integrated organic chemical plant 3) determination of water quality requirements and recycle/reuse potential for the manufacture of specific organic chemicals and 4) the assessment and development of oxidation, phase separation and adsorption treatment technologies for reuse/recycle applications. These operations are the begining steps in a search for viable methods for recycle/reuse systems for an industry as complex and atypical as the organic chemicals industry.

BARRIERS TO IMPLEMENTATION

We recognize the fact that even though recycle/reuse systems have all the potential benefits discussed earlier, industrial firms are usually reluctant to install these systems unless forced to by legislative requirements or other uncontrollable factors such as water shortages or high water costs. We therefore undertook a study to determine the types of "barriers" to acceptance of recycle/reuse systems by the industrial sector. The study concentrated on the organic chemicals industry, although most of the results are applicable to other industries as well. The information for this evaluation was obtained from existing published sources and from direct communication with representatives of the organic chemicals manufacturing industry. Specifically, valuable insights were provided by the Effluent Technology and Control Task Group of the Chemcal Manufacturers Association. One of the initial results was that due to the complexity and individuality of organic chemical plants, recycle/reuse systems would need to be site specific and evaluated on a case by case basis. This may not be true for other industries such as food processing and pulp and paper.

Four broad categories of barriers were addressed in our study namely 1) contamination concerns 2) purification technology limitations 3) cost considerations and 4) institutional barriers. The recycle of organic chemical process wastewaters can result in the build-up of undesirable materials or contaminants in the recycle streams. Potential problems caused by such contamination include alteration of reaction equilibrium, process efficiency, and catalalyst activity; degradation of product quality; equipment damage; and safety and health hazards.

Water used for a specific recycle/reuse application must be made available both in the quantity and quality demanded by that particular application. Whether the recycled stream is to be used as process water, cooling tower feed or even wash down there will be specific water quality requirements. Even advanced treatment technologies such as carbon adsorption, ion exchange, reverse osmosis and solvent extraction may not be able to purify the waste streams to the desired degree.

Cost can comprise a significant barrier to the adoption of waste water reuse/recycle options. The organic chemicals industry, as is true of any business enterprise is profit oriented, and management must be convinced that any venture undertaken will result in a positive return on investment. Thus, economic attractiveness will be a major factor in any decision regarding the adoption of recycle/reuse technology. In those cases where the level of treatment required for recycle/reuse is less than that required by applicable effluent limitations, a significant cost savings could result from the institution of recycle/reuse. However the opposite case would require additional expense which might be prohibitive. Cost concerns include such factors as cost of feasability studies & R&D, retrofit of existing facilities, equipment replacement and maintenance, monitoring costs, sludge and brine disposal costs, energy costs, and by product recovery.

Institutional barriers studied included 1) habitat protection laws and regulations 2) water allocation law and practice 3) inter-media pollution 4) government-private cost-sharing considerations 5) proprietary nature of R&D and 6) fear of the unknown. The importance of inter-media pollution should be stressed. Many recycle/reuse options involve removal of the pollutants from the plant wastewater and displacing them into the air or into the solid waste or plant sludge. In these cases the mandates of the Clean Air Act or RCRA would have to be adhered to and this might present a severe administrative and cost burden.

Now that we have identified many barriers the next step is of course the development of technology and methodologyto overcome the objections of industry to the use of recycle/reuse systems. This may prove to be a difficult task.

FUTURE WORK

What of the future course of our recycle/reuse research program? The program will proceed, within funding limmitations, in three directions: 1) execution of the next phase in the industries under study 2) initiation of recycle/reuse studies in additional industrial sectors such as metal finishing and 3) promotion of wider acceptance of recycle/reuse systems by the industrial sector. The last objective will of course require the direct participation of industry and pollution control equipment manufacturers in our efforts.

PB82-223439

INTEGRATED WASTE MANAGEMENT/CONTROL OF PRIORITY POLLUTANTS

- A MUST FOR WATER REUSE IN THE 1980s

Jon C. Dyer
President

Nicholas A. Mignone
Vice President
Environmental Technology Consultants, Inc.
6501 Loisdale Court - Suite 502
Springfield, Virginia 22150

INTRODUCTION

One of the most challenging tasks confronting the environmental pollution control profession during the 1980's will be the cost-effective, environmentally sound resolution of the waste solids. During the 1970's and with the enactment of the Federal Water Pollution Control Act of 1972 (PL 92-500), the national thrust was focused on improvement of water quality in the Nation's waterways. To reach this goal, the USEPA provides construction grants to build POTWs to meet applicable discharge requirements and established the NPDES permit program to control direct discharges to the Nation's waterways.

The enactment in 1977 of the Clean Water Act (CWA) (PL 95-217) and the subsequent promulgation of Federal regulations on industrial pretreatment (40 CFR 403) on June 26, 1978 will again impact industry in the 1980's. Effluent limitations placed on industries, both direct and indirect, will increase the costs of staying in business. Control of priority pollutants from industrial sources has become a major intent of regulatory agencies. Therefore, the treatment and handling of the industrial residuals generated will become a key issue in the 1980's.

The future of water reuse is directly impacted by the approach industry takes in meeting their regulatory responsibilities. The emerging concept of an integrated waste management approach within a community to serve both industrial and municipal needs could provide cost-effective solutions to these problems and further enhance the applicability of water reuse.

As industry solves its total environmental picture, the fate of priority pollutants cannot be overlooked. A water reuse project within an industrial complex has to be addressed within the total framework of current and future regulations impacting that industry. This approach to the question of integrated waste management should be included in the decision-making matrix for water reuse projects of the future.

In the 1980's, a major national thrust will be directed in the area of managing waste solids--both municipal and industrial. The CWA and several other major Federal laws impact the evaluation and selection of residuals management systems. These pieces of Federal legislation have refocussed environmental efforts. Table 1 lists the applicable Acts and breifly discusses the USEPA's role. The Federal regulations, coupled with applicable state and local requirements, have a major impact on proper selection of sludge management systems and should be considered in the evaluation of cost benefits of industrial water reuse projects.

The pretreatment regulations and the resulting program requirements impact both municipalities and indirect industrial dischargers. The following depicts the roles and responsibilities of EPA, NPDES States, POTWs and IUs:

- USEPA - Develops regulations, standards, and guidance for implementing pretreatment programs. Pretreatment Program Guidance [304(g)] is available through EPA. EPA Regional Offices are responsible for implementing states and local programs and enforcing categorical standards directly, where applicable.

- NPDES States - Administers and enforces pretreatment program requirements within their respective states. Where applicable, enforces categorical standards directly.

- POTWs - As required by 40 CFR 403, POTWs develop and implement local pretreatment programs to control industrial discharges into the municipal system and, where applicable, enforce categorical standards and installation of technologies.

- IUs - Industrial Users pretreat their wastes to meet appropriate standards, provide self-monitoring and reporting, and handle their industrial residuals (sludge) in a legal manner. The idea of pretreatment coupled with reuse potential has potential benefits.

Figure 1 represents an emerging thought process of total waste management that will become more obvious in the years to come as economic impacts play a larger role in solids management decisions. This concept of a total waste management scheme within a specific local jurisdiction is a logical step in achieving the most cost-effective solution to waste management. The POTW manager has to be the coordinator or focal point in resolving these issues. This concept of a total or better-stated integrated waste management will provide cost-effective alternatives to industries within a community and prove to benefit the entire area.

As depicted in Figure 1, the sludge generated at the POTW is greatly influenced by the industrial contribution into the municipal system. The nature, strength, and volume of industrial pollutants directly impact particular sludge management systems. Section 307 of the CWA authorized regulations (40 CFR, Part 403) and standards (40 CFR, Part 128) for industrial pretreatment. One of the objectives of the pretreatment regulations and standards is to reduce or prevent the introduction of pollutants into POTWs which will contaminate the sludge and thereby impair opportunities for the utilization and disposal of sludge. When industrial pretreatment regulations take effect, the amount of municipal sludges suitable for disposition via more cost-effective options should increase. For example, POTWs involved in landspreading practices should insist on effective pretreatment of appropriate industrial wastes in order to meet regulations designed to protect human health and the environment in a cost-effective manner. The resolution of the industrial residuals now comes into the picture.

In order to utilize the most effective sludge management techniques, a knowledge of influent characteristics, potential priority pollutants, sludges generated, industrial residues generated and applicable treatment and disposal options must be integrated into a decision matrix. This matrix provides all the ancillary information to assist managers in working together in selecting the best management option. From an industrial standpoint, whether a reuse project is feasible may depend on the costs of handling the residuals that would be generated and the problems associated with priority pollutants. The following concept should help promote reuse approaches.

PROCESS APPROACH TO INTEGRATED WASTE MANAGEMENT

A process approach is essential in solving the residuals questions within a specific community. A number of factors have to be considered, evaluated, ranked, and reviewed prior to arriving at a cost-effective and implementable solution. Consideration should include the development of a public information approach as well as the development of an advisory group. All these inputs are important in selecting the total waste management approach for the community. Table 2 is a detailed outline of factors to be considered and used in selecting the proper residuals management option.

As indicated in Table 2, a number of solutions are possible in solving the residual management question. Prior to selecting the approach to be used for a specified location and type of residuals generated and proceeding with an engineering design, serious consideration must be given to the institutional alternatives available. How these alternatives fit the specific local situation and conditions is a major factor in developing a successful total waste management approach. The alternatives range from a totally municipal operation to a totally private operation with a range of variations in between.

Basic Alternatives

Totally Public. This option involves an approach where all facilities, equipment, etc. are owned and operated by a public entity--municipality, county, public authority, etc. Financing is through available avenues--municipal bonds, authority bonds, county bonds, etc.--with each industrial user (IU) paying its proprotionate share of costs.

Totally Private. This option involves an approach where all facilities, equipment, etc. are owned and operated by a private firm. Financing can be through various programs--conventional loans, small business administration, corporate debentures, etc. Each user--municipal or industrial--pays its proportionate share of treatment/disposal costs.

Consortium. This option involves some combination of public and private ownership and operation of facilities, equipment, etc. A wide range of combinations from public ownership/private operation to private ownership/operaion and public control--is possible. These combinations need to be evaluated on a case-by-case basis and selected on their specific advantages and disadvantages under actual local conditions.

Figure 2 depicts the array of options available for managing residuals.

CONCLUSION AND SCENARIOS

The concept of solving the problem of waste residuals generated within a specific area by looking at cost-effective solutions, through an integrated waste management approach, is one that will prove beneficial in the 1980's. This approach could be very beneficial to water reuse projects. This paper identifies ideas and concepts that warrant further considerations. This approach was developed under contract with USEPA for the preparation of The Industrial Residuals Manual. This document is scheduled to be available in late 1981 and provides more detailed information concerning industrial waste residuals management and control. The manual is divided into three (3) volumes:

- Volume I - Overview of Industrial Residuals Management
- Volume II - Overview of Categorical Industries
- Volume III- Overview of Pretreatment and Sludge Management Technologies

Volume I contains information on management options available for dealing with residuals, a detailed discussion of legislative and regulatory considerations, and a concise summary (Fall 1980) of all available information known on the 129 priority pollutants. This volume also contains several scenarios depicting options available to small, medium, and large POTWs in addressing the industrial residuals problem.

Volume II contains the most current (Fall 1980) available information pertaining to the 34 categorical industries identified by USEPA to be addressed by Federal categorical pretreatment standards. This volume includes information on industry description, categorization, process description, wastewater characteristics, control and treatment technologies, type of residuals generated and residual management options.

Volume III contains discussions and descriptions of possible pretreatment and sludge residual treatment and management technologies applicable to the categorical industries. Many technologies have applicability to reuse.

It should be noted that The Industrial Residuals Manual is a state-of-the-art document. The information contained within the three volumes is constantly being updated and expanded. This document is based on the latest and most current data and information available.

In order to expand this concept, several scenarios are presented below that hopefully show the potential benefits, both economically and environmentally, to municipalities and their impacted industries. It should be noted that these scenarios are based on fictitious communities and do not address all the problems, solutions, or interactions that would exist in a real situation. These examples are not intended to promote any preconceived ideas or solutions but are intended to promote thoughts.

Scenario #1

POTW Description. Keithville is a small rural community--population approximately 3,400--located in the southeastern part of the U.S. The existing wastewater treatment facility consits of an Imhoff tank followed by a trickling filter system. Secondary effluent is discharged directly to a small creek. The treatment system has been overloaded for several years and violations of the Town's NPDES permit are frequent. The municipal sludge is dewatered on sand drying beds and disposed of in the county sanitary landfill. The Town would like to upgrade the treatment system and land-apply the resulting POTW sludge. The Town has applied to the State and the USEPA for construction grant funding.

Industrial Users. The only industrial user of the POTW is a relatively large non-ferrous metals manufacturing industry. This firm is the major employer in Town and a good working relationship already exists between the plant manager and the Town officials. The POTW regularly receives discharges from the industry that contain heavy metals and oil and grease. Due to the variety of plant operations, the discharge has a varying pH. In addition, batch process tanks are occasionally dumped into the POTW system. The industry is working to comply with applicable Federal pretreatment standards and has asked the Town to work with them. The main question to be resolved is the acceptable--environmentally and economically--disposal of the resultant residuals from the pretreatment processes.

Approach. The Town has elected to develop a local pretreatment program to comply with the General Pretreatment Regulation (40 CFR, 403). The Town manager has asked the Town's consultant to evaluate the impact of the industrial discharge, with pretreatment, on the proposed POTW system and determine if land disposal of the POTW sludge is a viable approach. The industry's consultant and the Town consultant (not necessarily the same) worked together to optimize the cost-effective solution for the industry and the Town. The Industrial Residuals Manual was a basic resource document. Volume II provided information on wastewater characteristics, residuals to be generated, and applicable regulations to be addressed in light of available disposal options. Volume III provided pretreatment and sludge residual treatment technologies.

Viable Alternatives. The conceptual approach (Table 2) was simplified for this particular situation. The viable alternatives were evaluated and the following decisions/selections were made:

- The POTW will develop and enforce a local pretreatment program.
- The POTW will work with the industry and assist in interfacing with the State.
- The POTW will expand its treatment facility and land-apply the municipal sludge.
- The POTW will charge the industry a user charge for treatment based on actual waste flows, concentrations, etc.
- The industry will install pretreatment, including flow equalization, neutralization, and dewatering and will reuse a substantial amount of the flow.
- The industry will apply to the State for approval of an on-site dewatered sludge land disposal system.

- The industry and the POTW will work together to meet all applicable standards and insure continued compliance.

Scenario #2

POTW Description. Midtown is a small mid-western Town of approximately 8,000 people. The municipal wastewater treatment system consists of a primary clarifier followed by a trickling filter. The facility is being upgraded by the addition of land treatment (slow-rate irrigation) prior to discharge into the local river. The sludge is applied to local farmland. The POTW has experienced periodic upsets in the past which have caused the POTW to violate its NPDES permit. During these upsets, the POTW sludge has had to be disposed of in the sanitary landfill. The State Health Department is disturbed over this practice. The POTW is developing a local pretreatment program as part of their construction grant responsibilities.

Industrial Users. The POTW accepts discharges from a number of nondomestic sources (meat packing, dairy, etc.) but has only one categorical industry--Diamond Industries, a small (12,000 gallon per day) electroplater. The plater has been in the POTW system for a number of years and has never been required to provide any form of pretreatment. Occasionally, various plating tanks have been batch dumped into the municipal system. The POTW has notified Diamond Industries of the Federal requirements for pretreatment and the Town's responsibility for enforcement. The shop manager is willing to work with the Town, but needs technical assistance and is depending on the POTW manager to help him.

Approach. The Town is committed to develop a viable local pretreatment program and protect the operation of the new municipal wastewater treatment facility. The POTW manager is working with all of the nondomestic dischargers in order to insure a smooth working program. The POTW manager and the shop manager for the plater get together to resolve the problem relative to Diamond Industries' compliance with Federal regulations and the local pretreatment program. The Industrial Residuals Manual is used as a resource document to answer questions as to the regulatory and legal responsibilities and management approach. Volume II provides information on the industrial process and the type of waste problems created. Volume III identifies treatment and disposal options.

Viable Alternatives. The conceptual approach presented in Table 2 was modified to fit their situation. The following alternatives were analyzed and selected to address the pretreatment needs for Midtown:

- The POTW pretreatment program will be developed and enforced equitably.
- The land treatment systems will be protected through pretreatment program compliance.
- The electroplater will reduce his flow to the POTW to below 10,000 gallons per day by installing inexpensive flow reducing valves on his rinse tanks.
- The plater will eliminate his cadmium line (major contributor to dump problems) because it represented less than 7 percent of his business and would increase his pretreatment costs.

- The electroplater will install pH controll on discharges to the POTW and discontinue batch dumping procedures.
- The POTW sludge will continue to be land applied by local farmers.
- The local pretreatment program and associated ordinance will provide a stable base for future industries that may choose to locate in Midtown.

Scenario #3

POTW Description. Jadfield is a City of approximately 75,000 people, located in the mid-Atlantic region of the U.S. The municipal wastewater treatment system consists of an activated sludge system followed by mixed-media filtration. The POTW discharges into a river with restrictive water quality standards. The plant is well operated, but has a history of intermittent NPDES permit violations. The sludge treatment system consists of thickening and incineration. Operational problems, due to high strength sidestreams from the sludge system, have caused some permit violations. The City has been denied the technique of land application of sludges due to the high metals content. The existing sanitary landfill is being closed by the State due to hazardous waste dumping by several area waste haulers. The City is concerned and has decided to address waste disposal problems within the local pretreatment program being developed. The POTW manager is progressive and is seriously considering a total waste management approach. The City feels that compliance with the pretreatment program being developed will protect the POTW and insure environmentally acceptable solutions to the waste disposal problem.

Industrial Users. The POTW accepts discharges from several categorical industries--electroplaters, metal finishers, a printing plant, a small pharmaceutical firm and several food-related industries. Residuals currently generated by local industry are collected by local waste haulers. The industrial discharges to the POTW do not seem to have adverse effects on the plant, with the exception of metals contamination of the POTW sludge. A few biological upsets at the POTW were thought to be due to industrial dumping, but the source could not be determined. The industrial community is happy with the labor market, transportation, and other benefits found locally, and is desirous to meet regulations and continue business.

Approach. The City is required by the General Pretreatment Regulations (40 CFR, Part 403) to develop an approvable local pretreatment program. The POTW manager has instructed the City's consultant to conduct an industrial waste survey (IWS) in order to obtain more information on the nondomestic users of the POTW. This information will be useful when using the Industrial Residuals Manual. The POTW manager, with approval from the City fathers, is developing an advisory group to assist in selecting viable alternatives to solve the total waste residual problem. The advisory group is comprised of the POTW manager, three industrial managers, and two representatives from concerned citizen/environmental groups. The technical team utilized the conceptual approach outlined in Table 2 and screened a number of treatment/disposal options. Several options were developed and presented to the advisory group. These options covered the question of both the municipal residuals (sludge/solid waste) and the industrial residuals.

Viable Alternatives. The process approach utilized was reviewed, evaluated, and accepted. A treatment and management option was selected. The final decision of ownership and operation has not been fully decided in regard to the industrial residual option. However, the following direction has been selected:

- All industrial dischargers will meet applicable pretreatment standards.
- The POTW will use a user charge system for recovery of collection and treatment costs for liquid wastes. Rates will be based on actual flows, concentration, etc.
- The POTW sludge will be acceptable for land application and the City plans to cease incineration of sludges and contract with local farmers for reuse of the municipal sludge.
- The City is working with the State to develop an acceptable sanitary landfill site and will control its use through the new City Ordinance.
- Several firms are reconsidering reuse approaches that were not cost-effective before and factoring these projects into the decision matrix each will use in meeting pretreatment requirements.
- A number of industries have compatible wastes and a form of centralized treatment and dewatering for the metal-type wastes appears to be cost-effective. The location, ownership, management, etc. has not yet been determined. Options available include: joint ownership, City owned and operated, industry owned and City operated, etc.
- The City and industry are working the State to develop an approved site for a segregated landfill operation which is specific for the metal residuals.
- Collection and hauling of residuals will be handled by local haulers on a competitive bid basis.
- A waste exchange program is being considered with other industries within the geographic region, in order to reduce residuals to be treated.
- The City and the industrial community in conjuntion with the advisory group will work together to insure compliance with all regulations, standards, etc.

ACKNOWLEDGEMENTS

The authors wish to acknowledge that much of the efforts and approaches discussed in the paper were supported by the USEPA as part of the development of a number of guidance documents to provide assistance to both municipalities and industries in meeting requirements of the CWA of 1977.

Table 1. Federal Laws Applicable to Sludge Management

- Clean Water Act of 1977, PL 95-217 (CWA) and the Federal Water Pollution Control Act of 1972, PL 92-500 (FWPCA). Authorizes Federal funding of up to 75 percent (85 percent for innovative and alternative technology projects) for the construction of wastewater treatment plants and sludge management operations; requires EPA to issue comprehensive sludge management guidelines and regulations; authorizes the NPDES (National Pollution Discharge Elimination SYstem) for point source discharges and development of areawide waste treatment or water quality management plans for nonpoint source pollution; and requires the implementation of pretreatment standards for industrial discharges that enter POTWs.

- Resource Conservation and Recovery Act of 1976, PL 94-580 (RCRA). Provides financial assistance to state and local governments for development of solid waste management plans; provides that technical assistance be developed for solid waste management methods; requires regulations involving the closure or upgrading of existing open dumps; requires regulations for the safe disposal of hazardous waste; and encourages the research and demonstration of more effective solid waste disposal and resource conservation technologies.

- Marine Protection Research and Sanctuaries Act of 1977, PL 92-532 (MPRSA). Phases out ocean disposal of sewage sludge by December 31, 1981. MPRSA also gives EPA the authority to determine a reasonable compliance schedule for the implementaiton of land-based disposal alternatives.

- Clean Air Act Amendments of 1970 and 1977, PL 91-604 and PL 95-95 (CAA). Authorizes the development of State Implementation Plans (SIPs) for the purpose of meeting minimum Federal ambient air quality standards. To meet the CAA objectives, EPA has developed an emission offset policy for new or modified incinerator facilities and a procedure for preventing the significant deterioration of ambient air quality. CAA also authorizes regulations for the control of hazardous air pollutants and new source performance standards.

- Safe Drinking Water Act of 1975, PL 93-523 (SDWA). Requires coordination with the CWA and RCRA to protect drinking water from contamination.

- National Environmental Policy Act of 1969, PL 91-190 (NEPA). Authorizes Regional Administrators, at their discretion, to require Environmental Impact Statements (EIS) (40 CFR), Part 6) if an adverse social, economic or environmental impact is suspected for a new or modified sludge disposition facility or practice.

- Toxic Substances Control Act of 1976, PL 94-469 (TSCA), Section 9. Requires coordination with the Clean Air Act and Clean Water Act to restrict disposal of hazardous wastes. Presently only PCB (polychlorinated biphenyl) is regulated in regards to sludge disposition. If a sludge contains greater than 50 ppm PCB then the disposition practice must comply with PCB regulations (40 CFR, Part 761).

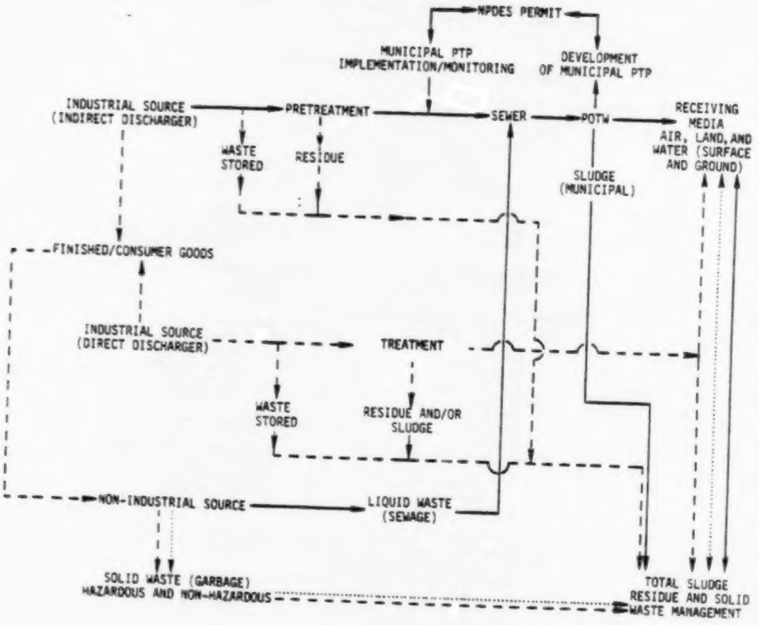
NPDES PERMIT
MUNICIPAL PTP IMPLEMENTATION/MONITORING
DEVELOPMENT OF MUNICIPAL PTP
INDUSTRIAL SOURCE (INDIRECT DISCHARGER)
PRETREATMENT
SEWER
POTW
RECEIVING MEDIA AIR, LAND, AND WATER (SURFACE AND GROUND)
WASTE STORED
RESIDUE
SLUDGE (MUNICIPAL)
FINISHED/CONSUMER GOODS
INDUSTRIAL SOURCE (DIRECT DISCHARGER)
TREATMENT
WASTE STORED
RESIDUE AND/OR SLUDGE
NON-INDUSTRIAL SOURCE
LIQUID WASTE (SEWAGE)
SOLID WASTE (GARBAGE) HAZARDOUS AND NON-HAZARDOUS
TOTAL SLUDGE RESIDUE AND SOLID WASTE MANAGEMENT

Figure 1. Concept of Integrated Waste Management

Table 2. Detailed Outline of Conceptual Approach for Solving A Residuals Management Problem

I. RESIDUALS INVENTORY DEVELOPMENT

- A. Educate and Involve Industrial Community
    - Seminars
    - Meetings
- B. Develop and Mail Industrial Questionnaire
- C. Use Residuals Manual to Develop Gross Volumes
- D. Follow-up
    - Phone
    - Site Visits (may require some industrial sampling)
- E. Development of Advisory Group
    - Technical
    - Legal
    - Financial
    - Industrial
    - Federal
    - State
    - Local Government
    - Civic

II. DEVELOPMENT OF ALTERNATIVES

- A. Categorization of Waste Residues
    - Quality
        - Hazard Classification
            - Known Composition
            - Leachate Analysis
        - Chemical Classification
    - Quantity
        - Weight
        - Volume
    - Geographical Origin
        - Quadrant Designation
    - Form
        - Liquid
            - Slurry
            - Cake
            - Solid
    - Generation Source
        - Industrial Classification
        - Process Classification
    - Resource Potential
        - Reuse
        - Recovery
- B. Management Options for Waste Residuals
    - Quantity Reduction
        - Thickening
        - Concentration
        - Compaction
        - Incineration
    - Stabilization
        - Biological
        - Chemical
        - Physical
    - Ultimate Disposal
        - Landfill
            - General
            - Segregated
        - Retention Basins
    - Reuse and Recovery
        - Internal Consumption
        - Supplier Return
        - Waste Exchange
        - Co-disposal
        - Reclamation
    - Internal/External Alternatives
    - Site Development Alternatives
        - Combined Sites
        - Segregated Sites
        - Centralized Sites
        - Noncentralized Sites
- C. Evaluation of Potential Sites for Treatment and Disposal Systems
    - Development of Criteria for Preliminary Selection
        - Geological and Topographical
        - Proximity to Residential and Commercial Development
        - Accessibility to Transportation Modes
        - Area Requirements for Treatment and Disposal Options
        - Relative Availability
        - Environmental Considerations
        - Ultimate Best Use Considerations
    - Application of Criteria for Selection of Potential Sites to Accommodate Screening of Alternative Systems
    - Consultation with Advisory Group on Findings
- D. Survey and Evaluation of Existing Treatment and Disposal Facilities
    - Industrial
    - Commercial
        - Within Area
        - Outside Area
    - Public
        - Municipal
        - County
        - State
- E. Evaluation of Logistic Alternatives
    - Transport Modes
        - Roadway
        - Rail
        - River
        - Conduit
    - Direct Delivery versus Transfer Stations
    - Centralized versus Noncentralized Disposal Destinations
    - Combined versus Segregated Disposal Destinations

Table 2. (Continued)

- F. Management and Operation Alternatives
  - Local Government
  - Local Authority
  - Industrial Consortium
  - Commercial
    - Lease
    - Ownership
- G. Monetary Screening
  - Determine Quantity of Units and/or Systems
    - Capital Facilities
    - Operation and Maintenance
  - Develop Unit and System Cost Basis
    - Capital Facilities
    - Operation and Maintenance
  - Establish Life-Cycle Procedure for Equating Capital Costs and Operation and Maintenance Costs to Common Cost Factors
  - Delineate Total Life-Cycle Costs for System Analysis Applications
- H. Nonmonetary Screening
  - Development of Ranking Methodology for Nonmonetary Factors
    - Environmental Effects
      - Aquatic Biota
      - Terrestrial
      - Wildlife Habitat
      - Cultural Areas
      - Air Pollution
      - Groundwater and Surface Pollution
      - Aesthetic
      - Land Use
      - Noise, Odor and Dust
    - Social Factors
      - Dislocation
      - Employment Changes
    - Contribution to Program Objectives and Goals
    - Energy and Resource Use
      - Energy
      - Land Commitment
      - Chemicals
    - Reliability
      - Frequency of Process Upsets
      - Frequency of Spills
      - Implementation Capabilities
        - Institutional
        - Financial
        - Legal
      - Risk and Functional Sensitivity
        - Acceptability
          - Public
          - Industry

III. SCREEN ALTERNATIVES FOR DETAILED ANALYSIS

- A. Select Alternatives for Detail Analysis
- B. Utilize Advisory Group
- C. Review

IV. DETAIL ANALYSIS OF VIABLE ALTERNATIVES
- A. Development Cost
- B. Capital Cost
- C. Operation Cost
- D. Maintenance Cost
- E. Social Cost

V. DEVELOP FINANCING AND USER COST ESTIMATES

VI. Implementation
- A. Implementation of Selected Alternatives
- B. Management
- C. Industrial Contracts
- D. Summarize Findings
  - Review with Advisory Group
- E. Finalize Study
  - Public Meeting

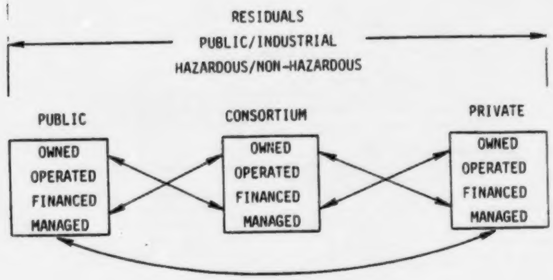
RESIDUALS
PUBLIC/INDUSTRIAL
HAZARDOUS/NON-HAZARDOUS
PUBLIC
OWNED
OPERATED
FINANCED
MANAGED
CONSORTIUM
OWNED
OPERATED
FINANCED
MANAGED
PRIVATE
OWNED
OPERATED
FINANCED
MANAGED

Figure 2. Residuals Management Options

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CONTRACTUAL REQUIREMENTS TO IMPLEMENT WATER RECLAMATION

Richard L. Anderton
Supervising Engineer

Norman G. Hixson
Vice President
James M. Montgomery, Consulting Engineers, Inc.
250 N. Madison Avenue
Pasadena, California 91101

INTRODUCTION

Southern California has long been accustomed to a plentiful fresh water supply and not cognizant to the need for developing municipal wastewater reuse alternatives. Fresh water supplies, which are taken for granted, have placed reuse at an economic and developmental disadvantage. Major sources of water to the City of Los Angeles such as those from the Colorado River will be deminished by the implementation of the Central Arizona Project and claims of prior water rights by numerous Indian tribes. There have also been numerous delays in completing the State Water Project and legislative proposals could jeopardize the Owens Valley. Potential energy shortages add new concerns on top of decreasing new supplies of imported water. The importation of water particularly from northern California is energy intensive and the possibility of an inadequate energy source for all purposes, including pumping, must be an increasing consideration in regional water supply planning. However, the reuse of municipal wastewater is an old concept and is receiving increasing interest and experiencing a gain in momentum as a result of improved effluent quality through wastewater treatment plant upgrading, obvious shortages in new fresh water supplies and the associated increase in energy costs and because of numerous environmentally concerned organizations. Major contractual considerations in developing water reuse projects are quality, quantity, price and health concerns of the water supplied. These questions were addressed in a major reuse market survey and the findings developed during that study are expanded in the following sections.

MARKET SURVEY

The implementation of a reclaimed water supply project will involve a multiple party contractual relationship between the producing agency, the distributing agency and the end user. This is based on the premise that a reclaimed water supply represents a substitute for normal potable supply. The production and distribution of reclaimed water may be performed by an agency other than the regular water purveyor(s) within the area due to the regional nature of many wastewater collection and treatment systems. To protect freshwater purveyors of potable water from finanical loss (effecting outstanding debt and overhead), contractual conditions related to reuse pricing, restitution for damage, quality and quantity requirements, and backup supply for reliability purposes are necessary in the development of end user contracts. Relationships of this nature will represent a departure from normal producer/consumer relationships which have been practiced by the water supply industry for many decades.

QUALITY AND QUANTITY

There are a variety of specific contractual requirements that must be considered in the implementation of a water reuse program. These will be somewhat different depending upon which water reuse category the particular user falls in. Industrial applications demand different contractual arrangements than will green belt and agricultural uses. Industrial reuse necessitates a greater emphasis on consistent quality than green belt and agricultural uses. Both are sensitive to supply quantity and reliability. Therefore, two major elements of a reuse contract are quality and quantity. A consistent quality is essential for industrial applications and highly desirable for green belt and agricultural uses. Large fluctuations in quality may cause plant or process upset in industry, or damage to and loss of plants in the case of landscape irrigation.

Quality monitoring requirements are essential. The quality indicated in the contract will likely be allowed to vary over a range and, therefore, periodic testing will be required to assure compliance with the terms of the contract. Quality testing and the party who bears the laboratory costs should be clearly spelled out in the contract to avoid future contests. Likewise, monitoring of reuse practice at the site of use will be required of the agency or the user. The formats of reports, frequency and responsible party should be defined in the contract. Related to this is the responsibility for ensuring compliance with local, state and federal environmental and health constraints. All of the foregoing are extremely important points that should be clearly defined.

Quantity requirements are linked closely to the reliability of the reclaimed supply and to the availability of a backup source of water. Reliability is extremely important to industry in maintaining productivity and is also important to agriculture and landscape irrigation because many plants cannot survive for long periods without regular irrigation. Two associated elements of quantity in the user contract are reliability and provision for backup source. Issues of additional storage, either at the reclamation plant or at the individual user site, and the necessity to maintain a stand-by connection to the potable water system will have to be addressed by the contract. Contractual relationships should clearly stipulate the responsibility for meeting additional storage requirements and the responsibility of maintaining a stand-by connection as an alternate supply of water. Stand-by connections may be a source of controversy, in that charges are usually levied by a supply agency even though there may be no deliveries made through the stand-by connection. Furthermore, if the owner must maintain a stand-by well, the annual maintenance and sunken capital cost is likely to be a contentious issue in the development of an equitable contractual relationship.

PRICING

The most fundamental requirement is to explicitly establish the basis of cost of water to the user. Pricing methodology should be clearly stipulated, including adjustments for inflation and reliability failures, so they can be understood by all parties. Additionally, parties to the contract must be protected against default. The supplier has made a large investment in the treatment, distribution, metering and possibly on-site costs to encourage reuse applications. Likewise, the end user has made a significant commitment for the principal benefit of the general public by agreeing to use reclaimed water. Unlike potable water supply, the potential uses of reclaimed water are limited and are nearly always site-specific. Financial planning and pricing strategies for reuse must accomodate this diversity among existing water purveyors and users. Due to quality limitations reclaimed water will often involve pricing practices that differ from potable water pricing practice. For example, cooling water may require a price different from rinse water even though served from a common system. To maintain equity among a number of different potable water purveyors served by a common reuse distribution system, it will be necessary to effect non-uniform wholesale water rates to the different purveyors. This is required because the existing source of supply cost diversity that exist between purveyors.

In the case of regional of even sub-regional circumstances, where reclaimed water supply is produced and distributed by one party to end users within the service territory of the regular purveyor (a third party), agency responsibility considerations including most of the end user conditions will also require contractual clarification. In addition, resolution of the financial impact on such purveyors should be developed and provided for. The responsibility of ongoing maintenance of the reuse system and the division of ownership of that system (where appropriate) should be defined in the contract. The point at which the delivering agency ceases to be responsible for system maintenance must be defined. Responsibility for meter reading, billing and normal customer service functions including accounting must be delineated. Each element of responsibility has a cost. Therefore, the division of responsibility must also provide for the terms of cost recovery.

HEALTH CONCERNS

One of the primary concerns of potential users is that of health risks associated with organic and inorganic reclaimed wastewater constituents. User concerns most often associated with industrial and landscape irrigation reuse are possible transfers of disease by pathogenic bacteria or virus, through contact or accidental ingestion. Organic compounds can readily be altered during many industrial processes into new and exotic forms. Some treatment processes for the removal of one organic constituent can transform other organics into more harmful forms. For example chlorination to control bacteria and viruses may alter relative harmless organics transforming them into halogenated organic compounds that may be carcinogenic. Most public health agencies have treatment requirements which will eliminate or minimize the possibility of disease transmission through the use of reclaimed water. Health restrictions and ordinances governing reuse activities further serve to protect public health. In addition to organic pathogens and virus, most municipal wastewaters contain a variety of inorganic toxic compounds. Inorganic compounds generally do not represent a problem because toxicity limits have been established for most of these compounds and treatment technology is available and understood to reduce or remove these constituents to acceptable levels.

CONTRACTUAL CONSIDERATIONS

The Orange and Los Angeles Water Reuse Study (OLAC) and the Green Acres Reuse Project for the Orange County Water District served as not only in assessing reuse potential but also as a basis for determining detailed contractual requirements necessary to implement a reuse program. During the development of these two studies over 350 various industrial and landscape irrigation users were individually contacted and interviewed regarding a variety of questions relating to reuse. Survey questions centered around user concerns that would eventually constitute contract requirements necessary to the particular user.

These basic requirements included water quality, quantity, pricing policy and health concerns.

WATER QUALITY AND QUANTITY REQUIRFMENTS

Of the potential users interviewed most would require guarantees of water within certain quality and quantity ranges in order to meet process or irrigation requirements. The survey further indicated that industrial quality requirements vary significantly with application but that requirements for landscape irrigation were more consistently similar. Water quality criteria differ in intent from the health and regulatory criteria. Health and regulatory criteria are directed towards protection of public health and receiving waters quality, the quality criteria are formulated to ensure that a reclaimed water user can operate successfully, i.e., that his green areas remain healthy and green, and that industries do not incur a loss of productivity due to process upset or alteration.

Industrial Applications

At the time of the survey there was no comprehensive list of quality requirements for specific industrial applications. This is due, in large part, to the variation of water use applications from plant to plant or even within a single plant, for similar processes. There is no "typical" industrial application. A second factor which handicaps attempts to place tolerance on limits of water constituents in industry may be tolerated is that the question is rarely addressed in practical operations. Industries for the most part utilize drinking quality water, with treatment utilized if a specific problem develops. Such treatment usually removes all or the majority of the offending constituents(s) and so a level of tolerance is never identified.

From the available literature and from communications with a variety of industries about the possibility of their utilizing reclaimed water, some generalities about industrial requirements have been developed and are described below. Major categories discussed encompass the largest water use applications identified during the Orange/Los Angeles County. Reference is made to Table 1 which presents the widely published 1972 National Academy of Sciences Industrial Water Quality Criteria values as modified by more recent observations and experience and, for comparative purposes, also presents the quality of effluent produced at a typical tertiary treatment plant within the OLAC study area. Requirements outlined in this table are intended to provide the reader with a general indication as to the suitability of his source of reclaimed water for a particular reuse application. It is obvious that it would do the supplier or the user no good to enter into a contract if the quality requirements of the user could not be reliably met.

Boiler Feed Water. High pressure boilers (1500 psig) have the most stringent water quality requirements of any major industrial use; however, as boiler pressure decreases, the quality requirements become less demanding. Scale formation and corrosion are the main potential problems. Calcium, magnesium, bicarbonate, sulfate, silica, and iron react to form insoluble salt deposits. Heat transfer may then be impaired and localized over-heating can occur. These deposits can also create corrosion cells with subsequent pitting of the metal underneath. The presence of oxygen, low pH, iron, or copper is the most common cause of corrosion in steam generation systems. To avoid or minimize these problems, pretreatment of potable water supplies is necessary for all but the lowest pressure systems (100 psig). Generally, softening plus demineralization is required above 600 psig, while solium zeolite softening is common for 100 to 600 psig systems. Mechanical and/or chemical deaeration is standard for all systems as is internal chemical treatment for further protection against corrosion and scale.

Many industries interviewed in the OLAC study area use boilers in the 30 to 150 psig range, but a few refineries and chemical plants have boiler systems operating around 400 to 650 psig. One steam electric power plant has a 1450 psig system. Reclaimed supplies could theoretically be utilized in these systems if it were presoftened to remove hardness, reduce silica, alkalinity, and TDS, and then put through existing or expanded on-site treatment systems. The practicality of switching from fresh to reclaimed supplies would depend on the extent to which the reclaimed water necessitated increases in internal treatment chemicals, system blow-down, and overall maintenance. Although reclaimed water has been successfully used in boilers operating as high as 2000 psig, in the general case, for systems above 150 psig, the cost of altering or expanding the existing pretreatment systems and internal treatment regimes which are geared to fresh water supplies, would likely be prohibitive.

Textiles. In the textile industry, water constituents of concern were found to be calcium and magnesium. These can interfere with soaps in the washing steps or may precipitate some dyes and causing irregularities from batch to batch of dyed product. Certain dyes may chelate metals, again resulting in irregular dyeing, although levels of most metals found in either fresh or reclaimed water are not likely to cause any noticeable effect. Iron and manganese, however, may cause staining, and will be required to be maintained at low levels. Organic matter and microorganisms could possibly lead to staining, odors, and growths on the textiles.

Textile dyeing industries interviewed in the OLAC study area for the most part utilized available potable supplies with no problem. A few, however, did provide sodium zeolite softening, and this would certainly be a minimum requirement for use of reclaimed water. From Table 1, it can be seen that lime softening for reduction of calcium, magnesium, and TDS would probably be necessary. Such softening would also reduce iron and manganese down to acceptable levels.

Paper Products. As the grade of paper produced becomes finer, water quality requirements become more stringent with respect to color, turbidity, and suspended solids. Organics and microorganisms are undesirable if they cause slime or growth on the product. Hardness is also a potential problem as it may react with sizing compounds (fill or stiffening materials) to cause precipitation of calcium carbonate.

As might be expected from consideration of Table 1, paper manufacturers interviewed who produced lower grade paper products, (i.e., ground wood paper, soda and sulfate pulps, and unbleached kraft paper) are amenable to using reclaimed water. No further treatment is considered necessary prior to use for these industries. On the other hand, producers of fine paper are generally not interested in using reclaimed water as even low levels of color, organics, and turbidity are likely to affect the quality of their products.

Plating Industry. A large proportion of plating industry water (60 to 90 percent) goes to stripping or pickling solutions, cleaning and rinsing the metals in preparation for plating, and for final rinsing after the plating. In the general case, these wash and rinse baths do not have high quality constraints. Just as with the paper and pulp industry, however, the finer the product, the more important is the water quality. In general, anything which is able to adhere to the metal surface will result in uneven or pitted coating. Thus, oil and grease, high suspended solids, turbidity, or dissolved solids may cause problems. Similarly, calcium and magnesium may precipitate as scale on the heated metal surfaces and create a rough finish. Because of the variability in temperatures, solution strengths, etc., found within the plating industry, limiting concentrations for specific constituents are not identified. Rather, constituents which are found to react with, cause deposit upon, or interfere with the plating solutions, are dealt with as the problem develops and is isolated. For example, iron has been identified as causing such problems in nickel-sulfate baths, copper solutions, chromium, and zinc baths. Small, single-bath cationic ion exchangers may be utilized for iron removal in water used to rinse just ahead of such plating baths and for making up the plating solutions themselves. In extreme cases where the final products may be required to resist heat or pressure stress, such as in the aerospace industry, demineralized water may be used for all of the baths. A more generally observed practice to avoid carryover of potential problem constituents is to utilize demineralized water in the final rinses just ahead of the plating baths.

Most of the plating facilities visited within the OLAC study area foresee no problems with utilizing the available reclaimed supplies for many of the stripping, wash, and rinse baths. As a conservative estimate, it appears that approximately 75-85 percent of this industry's water supply could be replaced with reclaimed supplies. As a precautionary measure, it would probably be wise to retain the use of potable and/or demineralized supplies for one or two rinses ahead of the plating baths and in making up the plating solutions themselves.

Cooling Water. Major concerns in cooling water applications surveyed are scale, corrosion, biological growth, fouling and delignification. Scale is caused primarily by the precipitation of hardness ions, calcium and magnesium, with phosphate, sulphate, and/or silica, on heat-exchange surfaces. The result is a reduction in heat-transfer efficiency. Biological growth is stimulated in cooling towers by the presence of phosphorous and nitrogen nutrients in a warm, moist environment. Fouling, or deposition of biological growth alone can decrease heat-transfer efficiency, but additionally, suspended solids and turbidity may adhere to the deposits and further retard heat-transfer and interfere with water flows. Corrosion is accelerated by low pH, dissolved solids, high anion levels, (especially chloride and sulfate ions,) and biological growth. These problems are generally controlled in cooling towers by reducing the levels of contaminants in the incoming make-up water, and further treating the recirculating water with dispersants, biocides, and corrosion inhibitors. Delignification is a problem deriving from the presence of sodium carbonate, but can be controlled by maintaining pH between 6.5 and 7.5.

Chemical Industry. Nearly 80 percent of the chemical industry's water use is for cooling, and with some modifications, the water quality criteria for this application will generally apply. Some modifications may be necessary because the chemical industry's process temperatures are normally somewhat higher than occur in the petroleum industry and steam electric power generation. In addition, the cooling water is normally applied to the shell as opposed to the tube side of the heat exchangers with a correspondingly lower velocity of flow. These two conditions will act to encourage settling of organics and sludge deposits, and so suspended solids, organics, silica, and hardness may have to be decreased and carefully monitored, or internal chemical treatment will have to be increased.

Process water within the chemical industry was found to be more critical and product specific. Whether or not reclaimed water is suitable for use is thus a case by case determination. At least one inorganic chemical manufacturer interviewed could use reclaimed water as process water; however, most or all of the organic chemical manufacturers could not.

Glass Production. In glass container manufacturing, most of the water is used to carry defective products away from the assembly line and into a quench tank. This continuous flow utilizes a significant amount of water. Large quantities and reliability in supply are primary requirements in this use. Quality, however, is not a major factor, and reclaimed water would be very appropriate. Other potential reclaimed water applications within this industry would be in cooling towers and for air scrubbers. Cooling tower quality requirements have been discussed previously, and air scrubbers would simply require a quality which would not plug spray nozzles, i.e., low suspended solids and control of nutrients.

Primary Metals. Water quality requirements for the primary metals industry are variable, depending upon whether the water is used for quenching and hot-rolling, cold-rolling, or rinse water. Regardless of the point of use, however, the criteria are not demanding, although some rinse waters may be softened. In general, the water quality requirements are as shown in Table 1.

Bethlehem Steel in Sparrows Point, Maryland, has since 1942 used reclaimed effluent from Baltimore's Back River Treatment Plant for virtually all of its process water. Kaiser Steel in Fontana, California, utilizes its own wastewaters for make-up to processes and cooling.

Oil Well Injection for Repressurization. There are several oil well injection sites in the OLAC study area. Those contacted indicated fairly stringent quality requirements. The main problem to be avoided is well clogging from suspended solids and biological growth. The resulting specifications for very low levels of constituents such as ammonia, organic chlorides, and phenols (see Table 1) are not normally met by most available filtered secondary effluents, and would be met only by specialized tertiary treatment processes.

Landscape Irrigation

The use of reclaimed water for landscape irrigation is governed by chemical characteristics of the water that affect plant growth and survival, soil conditions, and the underlying ground water. The chemical parameters of major importance are salinity, sodium adsorption ratio (SAR), concentrations of specific ions known to have toxic effects on plants and trace elements. These parameters interact with each other and with local conditions such as soil permeability, plant types and irrigation practices such that there is no absolute standard by which their combined effect can be evaluated. As opposed to the extensive quality requirements for industrial reuse, these three characteristics are the paramount concerns for landscape irrigation with reclaimed water. The University of California Cooperative Extension guidelines presented in Table 2 do, however, provide a useful and widely accepted guide for evaluating the suitability of irrigation water and identifying areas of potential concern. The general significance of salinity, sodium adsorption ratio, specific ion toxicity, and trace constituents is discussed below.

Salinity. Salinity is a vital consideration for irrigation waters. If the salinity exceeds the level of tolerance for a specific plant, osmotic regulation by the root membrane will inhibit the adsorption of water. The plant will then dehydrate and wilt even though the soil shows an apparent excess of moisture.

The salinity of irrigation water is commonly reported in electrical conductivity units (EC) or total dissolved solids (TDS). The potential hazard to landscape ornamentals and agricultural crops can roughly be determined from the following table. The hazard of moderate salinity levels such as these can be operationally controlled by leaching. This washes salts below the root zone before toxic accumulations can occur.

GUIDELINES FOR SALINITY IN IRRIGATION WATER

Classification	TDS, mg/l	EC, mmhos/cm
Water for which no detrimental effects are usually noticed	500	0.75
Water than can have detrimental effects on sensitive crops	500-1000	0.75-1.50
Water that can have adverse effects on many crops, requiring careful management practices	1000-2000	1.50-3.00
Water than can be used for tolerant plants on permeable soils with careful management practices	2000-5000	3.00-7.50

Sodium Adsorption Ratio. SAR is a criterion developed by the U.S. Salinity Laboratory for evaluating the sodium hazard in water. It measures the ratio of sodium to divalent magnesium and calcium cations in the soil and is calculated as follows:

$$SAR = \frac{Na^{+}}{Ca^{++} + Mg^{++} \ /2}$$

In the proper ratio, calcium and magnesium in the soil indicate that the soil will be granular in texture, easily worked and permeable. With increasing proportions of sodium the soil will tend to become less permeable and water logging may occur.

An adjusted equation for the SAR includes the effect of precipitation or dissolution of calcium in soils and the content of carbonate (CO_3) and bicarbonate (HCO_3) alkalinity in the water. The formula for computing the adjusted SAR may be found in current literature.

Specific Ion Toxicity. Boron toxicity in many areas can be traced to the use of irrigation waters with a boron concentration in excess of 1 mg/l. At the present time there is no economically feasible method of removing boron from irrigation water. Similarly, there is no chemical or soil amendment which can economically be added to the soil to render it nontoxic. However, marginal problematic boron, like salinity concentrations, can be alleviated somewhat by irrigating slightly in excess of plant consumptive use. Overall, boron is not expected to be a quality problem for anticipated uses within the study area but would have to be evaluated in other study areas.

Table 2 shows increasing problems of foliar deterioration and leaf scorching for chloride concentrations between 142 and 355 mg/l, if the ions are adsorbed by the roots, and for concentrations above 106 mg/l if spray irrigation is used and the ions adsorb to the leaves. While sodium in small quantities may be beneficial to plants, similar leaf scorch observations have been made for irrigation waters high in sodium (greater than 69 mg/l). The effluents for which data exist contain 110, 120 and 122 mg/l of sodium. Potential problems can be alleviated by excess irrigation or by occasional use of domestic water backup systems for irrigation.

Trace Elements. In addition to the major chemical quality requirements, numerous trace elements in reclaimed water may affect plant growth. Recommended maximum concentrations of various trace elements in irrigation water are presented in Table 3.

PRICING POLICY

A major requirement of the contract, is the development of a formula guaranteeing an advantageous delivery price for reclaimed water. Most users contacted stated that they would require a lower cost for reclaimed water than that of existing fresh water supplies. This can be presented in terms of a minimum savings over the prevailing cost of existing supply which would be determined on an individual user basis. Either no capital investment by users for on-site improvement, or a greater reduction in future water cost would serve to reimburse the user for any on-site capital investment including interest.

In the OLAC Water Reuse study, the costs and pricing practices of the principal water purveyors within the study area were surveyed. For the purpose of relating purveyor costs to pricing practices, considerable data were obtained from 51 retail purveyors within the study area. In addition to cost data, water sales revenue, metered water sales, and rate structure applications, were analyzed to determine typical pricing practices.

The fiscal 1978 average unit retail price paid by the consumers of each system were developed to determine the range of average consumer cost differences within the study area. The full range of average unit retail prices of 51 purveyors surveyed is presented as follows:

	Retail Price 1978 ($/ac-ft)
Low	120
Average	199
High	444

From the above table it can be seen that a uniform pricing structure for the sale of reclaimed water may not be feasible. This spread in retail potable water prices within the study area seems to indicate that a non-uniform pricing policy will have to be adopted. The survey of retail purveyors' prices indicated that price structures within an individual agency also vary. Therefore, whether the reclaimed water distribution system covers just a single purveyor or is more regional in nature and covers several agencies, it is apparent that a non-uniform pricing policy will need to be adopted by the agency purveying reclaimed water.

Under such a non-uniform pricing structure, the price to each user would be negotiated and stipulated within the contract. The market survey for the OLAC study area indicated that a minimum price reduction of 15 percent would be required below potable water rates. This differential represents a number of different things to each user. The reduction, in some cases, represents the incentive required to consider reuse and, in other cases, it represents the cost "aggravation" to modify or remodel industrial processes. This differential to other users represents a means of recovering capital investment for on-site reuse facilities. While 15 percent is representative of the OLAC study area, the individual figure for each user may be different and would have to be re-evaluated for other study areas. This type of non-uniform pricing structure is relatively new to the reclaimed water business. While it represents a departure from accepted pricing policies, it appears to be the most feasible means of implementing an equitable price (cost savings) for each user when involved in a Regional reuse program.

HEALTH ASPECTS

During the interviews there were numerous questions related to the health related aspects of utilizing reclaimed water. Many of these questions and concerns are already in reuse guidelines and addressed treatment requirements. All of the users contacted were informed that certain operating constraints will be imposed for the use of reclaimed water. For example, no cross connections will be allowed, tables and drinking fountains will have to be wiped down with a chlorine solution if they are in the spray of reclaimed water, and signs will have to be posted indicating non-potable supplies. The contract should clearly delineate all requirements that health authorities may impose on the distribution and use of reclaimed water. This will include both the initial requirements affecting design details and the on-going periodic requirements, including monitoring and reporting. Both the initial and monitoring/reporting requirements can affect the users and their respective costs and should be understood by all parties. The terms of the user contracts should contain a clear delineation of responsibility for meeting these requirements.

SUMMARY OF CONTRACT REQUIREMENTS

Appendix A represents a sample reuse contract between a reclaimed water supplier, a retail municipal purveyor and a private country club for the purpose of providing reclaimed water in lieu of fresh water for golf course and landscape irrigation. This draft document is not intended to be a final legal contract but is intended to illustrate the basic points required under a reuse contract. This is by no means complete, and various additional items would have to be negotiated and added to the document based upon the requirements of the several municipal purveyors and users. Individual contracts should be written that are tailored to specific users and their purveyors. The final working contract must adequately spell out and define responsibilities of all parties, and serve to protect the wholesale supplier, the municipal retail supplier and user on an equitable basis. The key to implementing water reuse is the careful drafting and negotiation of an adequate reuse contract. The ultimate commitment by the user to purchase water and by the supplier to deliver it is paramount to a successful reuse program.

A review of "Legal Issues in Implementing Water Resuse in California," authored by Ernest C. Brown and Nathaniel Weinstock, (Ecology Law Quarterly, Vol. 9, 1981), indicates substantial indecision in regard to the legal theories which may be applied by the courts in cases involving reclamation accidents and damages resulting from reuse of reclaimed municipal wastewater. The principal legal theories that might apply and are discussed in detail in the above paper include; strict liability in tort for defective products (product liability), breach of warranty (expressed or implied), strict liability for ultrahazardous activities, and negligence.

An important aspect in developing an adequate contract to implement reclamation is consideration of contract liability. It is not the intent of this paper to fully develop the legal implications and liabilities that could arise out of the disputed reuse contract. However, it is important to point out these issues to agencies that are considering entering into reuse contracts with users. By pointing out potential issues to those developing the reuse contract, some problems can be minimized or eliminated.

The municipal water purveyor may wish to be directly included in a three party contract and also may want to assume a strong negotiating role with the user. In other cases, the municipal purveyor may not have the manpower or the inclination and would prefer that reclaimed water supply agency assume this responsibility. Regardless, it is believed the municipality should officially sanction the Supplier-User agreement in a separate contract. The agreement should be carefully prepared to safeguard against the possibility of future disputes concerning authority and/or territorial service perogatives. The contract is the key legal instrument that brings together in a concise and clear manner the specific needs of the user and the obligations of the purveying agency to implement a successful reuse program.

TABLE 1

INDUSTRIAL WATER QUALITY REQUIREMENTS[a]

Constituent[d]	Cooling Water Makeup	Textiles	Tanning	Boiler Feedwater (psig) 0-150	150-700	700-1500	1500-5000	Primary Metals	Pulp and Paper groundwood	SW	Unbleached	Kraft Bleached	Fine	Oil Well Injection	LA-Glendale 1978
Silica (SiO$_2$)	50			30	10	1.0	0.01		50	20	100	50	20	15	21
Aluminum	0.1			5	0.1	0.01	0.01		0.3	0.1	1.0	0.2	0.1		0.17
Iron	0.5	0.1	50	1	0.3	0.05	0.01		0.1	0.05	0.5	0.1	0.05	<1[c]	0.20
Manganese	0.5	0.01	0.2	0.3	0.1	0.01									0.03
Copper		0.05		0.5	0.05	0.05	0.01								0.02
Calcium	50	10	60		0	0	b			20			30		49
Magnesium		5			0	0	b			12					15
Sodium															110
Potassium															15
Ammonia				0.1	0.1	0.1	0.1							1	13.4
Bicarbonate	25	200		170	120	50	b								240
Carbonate														0	
Sulfate	200	100	250											50	133
Chloride	500	100	250					175	75	75	200	200	--		105
Fluoride	500														1.03
Nitrate															0.9
Phosphate	4													5	5.5
Dissolved Solids	500	100		700	500	200	0.5	1000	500	250	500	300	200	10,000	585
Suspended Solids	100	5		10	5	0	0	<50						2-5	11
Hardness (CaCO$_3$)	130	25	150	20	1.0	0.1	0.07	500	200	100	200	100	100		
Alkalinity (CaCO$_3$)	20			140	100	40	0		150	75	150	75	75		
Acidity (CaCO$_3$)															
pH (units)		6.0-8.0	6.0-8.0	8.0-10.0	8.0-10.0	8.2-9.2	8.8-9.2	6.0-7.0						6-8.0	7.0
Color (units)		5	5						30	5	100	25	10		
Organics															
MBAS	1							30							0.4
CCl$_4$	1													8	
organic chlorides														0	0.0007
phenols														0	0.01
COD	75	8		5	5	0.5	0							5	38
Dissolved Oxygen				<0.03	<0.03	<0.03	<0.005								
Temperature	100			120	120	120	120	100							
Turbidity (t.u.)		0.3-25	0	10	5	0.5	0.05		5	2.5	10	4	1		1.7

[a] Modified from the 1973 NAS Industrial Water Quality Criteria

[b] Determined by treatment for other constituents

[c] Total metals <1

[d] Units in mg/l unless otherwise specified

TABLE 2

UC COOPERATIVE EXTENSION GUIDELINES FOR INTERPRETATION OF QUALITY OF WATER FOR IRRIGATION

Problems and Related Constituent	Water Quality Guidelines[a] No Problems	Increasing Problems	Severe
Salinity[b]			
EC of irrigation water, mho/cm	<750	750-3,000	>3,000
Permeability			
EC of irrigation water, mho/cm	<500	500-2,000	>2,000
SAR[c]	<6.0	6.0-9.0	>9.0
Specific ion toxicity[d]			
From root adsorption			
Sodium (evaluate by SAR)	<3	3 - 9	>9
Chloride			
meq/l	<4	4 - 10	>10
mg/l	<142	142 - 355	>355
Boron, mg/l	<0.5	0.5 - 2.0	2.0-10.0
From foliar adsorption[e] (sprinklers)			
Sodium			
meq/l	<3.0	>3.0	—
mg/l	<69	>69	—
Chloride			
meq/l	<3.0	>3.0	—
mg/l	<106	>106	—
Miscellaneous[f]			
NH_4 as N mg/l for sensitive crops	<5	5 - 30	>30
HCO_3 (only with overhead sprinklers)			
meq/l	<1.5	1.5 - 8.5	>8.5
mg/l	<90	90 - 520	>520
pH	Normal range	6.5 - 8.4	--

[a] Interpretations are based on possible effects of constituents on crops and/or soils. Guidelines are flexible and should be modified when warranted by local experience or special conditions of crop, soil, and method of irrigation.

[b] Assumes water for crop plus needed water for leaching requirement (LR) will be applied. Crops vary in tolerance to salinity. Refer to tables for crop tolerance and LR. The mho/cm x 0.64 = approximate total dissolved solids (TDS) in mg/l or ppm.

[c] SAR (sodium adsorption ratio) is calculated from a modified equation developed by U.S. Salinity Laboratory to include added effects of precipitation and dissolution of calcium in soils and related to CO_3 + HCO_3 concentrations.

[d] Most tree crops and woody ornamentals are sensitive to sodium and chloride (use values shown). Most annual crops are not sensitive (use salinity tolerance tables). For boron sensitivity, refer to boron tolerance tables.

[e] Leaf areas wet by sprinklers (rotating heads) may show a leaf burn due to sodium or chloride adsorption under low humidity/high evaporation conditions. (Evaporation increases ion concentration in water films on leaves between rotations of sprinkler heads).

[f] Excess N may affect production or quality of certain crops; e.g., sugar beets, citrus, avocados, apricots, etc. (1 mg/l NO_3 as N = 2.72 lbs. N/ac-ft of applied water.) HCO_3 with overhead sprinkler irrigation may cause a white carbonate deposit to form on fruit and leaves.

TABLE 3

RECOMMENDED MAXIMUM CONCENTRATIONS OF TRACE ELEMENTS IN IRRIGATION WATERS

Element	Maximum Concentration[a]	
	For Waters Used Continuously All Soil	For Use up to 20 Years on Fine Textured Solids of pH 6.0 to 8.5
Aluminum (Al)	5.0	20.0
Arsenic (As)	0.10	2.0
Beryllium (Be)	0.10	0.50
Boron (B)	0.75	0.05
Cadmium (Cd)	0.010	0.05
Chromium (Cr)	0.10	1.0
Cobalt (Co)	0.050	5.0
Copper (Cu)	0.20	5.0
Fluoride (F)	1.0	15.0
Iron (Fe)	5.0	20.0
Lead (Pb)	5.0	10.0
Lithium (Li)[b]	2.5	2.5
Manganese (Mn)	0.20	10.0
Molybdenum (Mo)	0.01	0.05[c]
Nickel (Ni)	0.20	2.0
Selenium (Se)	0.02	0.02
Vanadium (V)	0.10	1.0
Zinc (Zn)	2.0	10.0

[a] Expressed as milligrams per liter. These levels will normally not adversely affect plants or soils. No data available for mercury, silver, tin, titanium, tungsten.

[b] Recommended maximum concentration for irrigation of citrus is 0.075 mg/l.

[c] For only acid, fine textured soils or acid soils with relatively high iron oxide contents.

DRAFT
AGREEMENT

This AGREEMENT, made and entered into this _______ day of ____________, 1981, by and between the LEAKY PIPE WATER DISTRICT, hereinafter referred to as "District", the CITY OF ROCKS, hereinafter referred to as "City", and the BIGWIG COUNTRY CLUB, hereinafter referred to as "User".

WITNESSETH THAT:

WHEREAS, District created under special act of the California Legislature in 1933, was formed for the purpose of protecting and managing the County ground water basin water resources. The enabling act legislation specifically empowers the District to manage the ground water basin; provides for conservation of the basin, including both quality and quantity of water; provide protection of the County's water rights and the natural flow of the River.

WHEREAS, District, purchases imported water for spreading and replenishment; receives treated wastewater from the County Sanitation District for further renovation-reclamation and ground water injection.

WHEREAS, District is authorized to sell or otherwise put to beneficial use any water or reclaimed wastewater recovered from the operation of said water reclamation plant, and

WHEREAS, reclaimed water currently produced at District Water Reclamation Plant is suitable for a number of nonpotable uses including, but not limited to, landscape irrigation; and

WHEREAS, District is currently planning and intends to construct a pipeline system for the distribution of reclaimed wastewater to User within the boundaries of City; and

WHEREAS, City has heretofore supplied User with water from the City's potable water system at the rate(s) specified in City Ordinance No. _________; and

WHEREAS, User operates a golf course requiring irrigation water in all amounts ranging from 200 acre feet to 250 acre feet annually; and

WHEREAS, the use of reclaimed water for golf course irrigation is of mutual benefit to User, the City and to the District in fulfilling their joint responsibilities for the conservation of natural resources in accordance with Sections 13550 and 13551 of the California Water Code; and

WHEREAS, User is willing to contract with City for the purchase of reclaimed water for irrigation purposes in lieu of potable water heretofore used for the same purpose; and

WHEREAS, City is willing to contract with District for the purchase and delivery of reclaimed water to User's premises and to contract with User for the sale of said reclaimed water; and

WHEREAS, District is willing to contract with City to deliver reclaimed water to User's premises subject to the terms and conditions contained herein;

NOW, THEREFORE, it is hereby mutually agreed by and between the parties hereto as follows:

1. Facilities for Delivery and Distribution of Reclaimed Water

District agrees to provide, at no cost to City, a distribution pipeline system from _____________________________ to _____________________ and metering device, said delivery point and metering device being adjacent to that City metering device presently used by City to deliver potable water to User. District further agrees to pay for the installation of such on-site facilities on User's premises as are necessary to the use of reclaimed water including such physical facilities as are required for the protection of public health.

City will permit the distribution system and ancillary facilities to be located in the public rights of ways, of City as shown on Exhibit "A" and in accordance with City's construction standards. Said distribution system will be owned, operated and maintained by District on behalf of City for the expressed purpose of providing User (City's customer) with reclaimed water service. It is understood that said distribution system may be constructed with capacity for other users within City's jurisdiction. At such time as District desires to provide additional service from said system or to extend service from said system, District and City will enter into separate agreements for each such service or extension in accordance with the intent contained in this agreement.

District will provide User or User's designated representative with the criteria necessary to meet public health requirements for design, operation and maintenance of the on-site reclaimed water systems. User agrees to design such on-site facilities in accordance with said criteria, obtain no less than three bids for construction of such facilities and present the plans and bids to District for approval prior to construction of such facilities. User agrees to permit District access to the site of work during construction for the purpose of periodic inspection to assure that said facilities are constructed according to approved plans. Following completion of construction District will release funds to User in payment of design and construction costs of said on-site facilities and User agrees to operate said facilities in accordance with rules and regulations of public health authorities and the other terms and conditions of this AGREEMENT.

2. Quantity of Reclaimed Water To Be Purchased

During the term of this AGREEMENT, City and User agree to purchase from District and District agrees to deliver to User for a consideration hereafter set forth not less than 200 acre feet per year and not more than 250 acre feet per year and subject to the other qualifications set forth herein.

It is understood and agreed by all parties that delivery of and purchase of said quantity shall not exceed 60 acre feet in any one month and at a maximum delivery rate of 120 gpm. If, on any particular day, District does not have available the quantity of water requested by User, District shall provide User with such lessor amount as is available. City agrees that User may take the difference between that amount of reclaimed water available and the amount User needs to operate the irrigation system efficiently (specified herein) from the City's potable system. To this extent potable water is purchased by User in such instances, User agrees to pay the then existing rate for water in accordance with the terms contained in City Ordinance No. ______ as it may be amended from time to time.

3. Quality of Reclaimed Water To Be Purchased

During the term of this AGREEMENT District agrees to deliver reclaimed water to User containing quality limits as set forth in Exhibit "B" attached hereto. To the extent that District may be unable to deliver water of this quality from time to time, User and City shall be notified by District what the quality constraints are. In the event User chooses not to take the lessor quality, User may substitute with potable water from City system as indicated in Section 2 for that period of time until District has restored the reclaimed water quality to the levels reflected in Exhibit "B".

4. Operating Obligations of the Parties

During the term of this AGREEMENT, District shall manage, operate and maintain the system as shown on Exhibit "A" in an efficient manner. Such operating responsibility will include the maintenance of quality, pressure and quantity as agreed herein, however, the limit of responsibility ends at the District side of User meter.

City agrees to assume ownership of, service, maintain and read User meter in the same manner it would for a customer meter service attached to its potable system. Such customer service functions also include User billing, collection record keeping and notification to District of the quantity used during each meter reading period. Upon receipt from City of the noticed amount of water used during each billing period, District will invoice City promptly in accordance with the pricing formulae set forth herein.

User agrees to operate and maintain the on-site system from City's meters to the point of application in accordance with the rules and regulations of public health authorities. Such rules and regulations are listed on Exhibit "C: attached hereto.

It is further understood by the parties, that all physical facilities originally constructed (including on-site facilities) by District and turned over to the other parties for maintenance, shall also become their individual and separate property and shall be maintained and replaced as necessary by the Owner.

5. The Price of Reclaimed Water

In recognition of benefits that accrue to all water users within the jurisdiction of District, it is the intent of this AGREEMENT to provide User with an incentive to use reclaimed water for irrigation purposes and at the same time maintain the City financially whole from the resulting loss in sale of potable water. To accomodate this intent the price of reclaimed water is adjusted to the cost of potable water as it will change from time to time.

For the term of this AGREEMENT City agrees to sell reclaimed water to User at a rate equal to 85 percent of the applicable rate for potable water that User would be charged under City Ordinance No. _______ as said ordinance including the rates for service shall be amended from time to time.

For the term of this AGREEMENT District agrees to price reclaimed water to City at an amount equal to City's prior fiscal year audited source of supply cost as further defined herein;

- Source of supply shall mean all sources of water developed and/or acquired by City for distribution in City's potable water systems during the immediate preceeding fiscal year.

- Audited cost shall mean all costs related to and associated with obtaining and introducing supply into City's distribution system, and shall include;

  a. The cost of supplemental water purchased from MWD and/or other suppliers;

  b. The power and O&M cost related to ground water well production and booster stations at the initial point of introduction to the distribution systems;

  c. Replenishment assessments related to ground water production;

  d. The annualized unit capital cost (depreciation) of wells, booster stations, metering stations and all related equipment, buildings and other facilities related to source of supply, including interest on the replacement value of land associated with such facilities.

  e. The cost of insurance, taxes and miscellaneous items related to all production facilities.

To the extent that City accounting practices do not presently delineate the costs itemized above, City and District hereby agree that reclaimed water charges for fiscal year 1982 shall be $_______ per ac.-ft. and thereafter shall be adjusted annually as provided for herein. District shall have the right to review the books, records and accounts of City during normal business hours upon 48 hours prior notice to City.

6. Billing and Payment for Reclaimed Water

Not later than five days after reading User's meter, City shall forward to District a statement of use indicating the current meter reading, the previous meter reading and total use during this period. Within ten days after receipt of the statement of use, District shall mail an invoice based on the unit charge established for that fiscal year. City shall promptly pay the amount invoiced on or before its due date, namely, the fifteenth day of the month following the mailing of the invoice by District.

User agrees to make payments to City for receipt of reclaimed water at the time and in the manner required by City Ordinance No. ________.

7. Limitation of Use

User understands and agrees that reclaimed water delivered by District pursuant to terms hereof has limited uses, and User agrees to use said reclaimed water for only those uses or purposes which are legally permissible under the laws of the state and the directives of the appropriate regulatory agencies. District will inform City and User of any change of which it shall become aware in said legally permissible uses which might affect the User's use of reclaimed water.

8. Term and Amendment

The term of this AGREEMENT shall be twenty (20) years from the day and year first written, provided that this AGREEMENT may be amended at any time by mutual agreement of the parties hereto. This AGREEMENT may be extended beyond the terms herein by mutual agreement of the parties hereto.

9. Limitation on Contractual Commitment

Nothing herein shall be construed to commit any portion of the effluent from District's Water Reclamation Plant beyond that usable by User. User shall not resell said effluent to another party or transfer the rights and conditions of this

AGREEMENT without the approval of District and said approval shall not be unreasonably withheld.

IN WITNESS WHEREOF, the parties hereto have executed this AGREEMENT on the day and year above set forth.

PB82-223454

TOWARD ZERO DISCHARGE FROM TEXTILE DYEING PROCESSES

Wayne C. Tincher
Professor

Linn Averette
Research Technologist
School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

INTRODUCTION

The textile industry uses approximately 125 billion gallons of water annually (1). Much of the process water is discharged with appreciable quantities of organic and inorganic chemicals (dyes, pH control agents, lubricants, surfactants, auxiliaries, oligomers, etc.) which require extensive treatment of the wastewater and which contribute to the pollution problems associated with textile processing. In the past, the textile pollution problem has been attacked by construction of waste treatment facilities. As requirements became more stringent, the waste treatment plant was expanded or additional treatment processes were added to meet the standards. This approach has consumed large sums of non-income-producing capital and has increased the operating costs of many textile plants. In addition, dyes present in textile processing wastewater are resistant to usual treatment procedures and constitute a particularly difficult problem for all treatment systems.

Two basic types of procedures are used for textile coloration -- pad-fix (continuous) processes and exhaust (batch) processes. Continuous dyeing is used primarily for long runs of a given fabric style. Because of their continuous nature and the use of relatively small volumes of dye liquor, these processes tend to be more efficient than batch processes. Exhaust batch processes are generally very inefficient in their use of chemicals, water and energy and generate large volumes of wastewater that must be treated. Despite these disadvantages, the versatility, ease of control, and short-run capability of exhaust processes enhance their desirability for coloration of many textile products.

In a conventional batch dyeing process the machine is filled with water, the goods to be dyed are entered, and the fabric moved through a bath (or a bath moved through the goods) to saturate the material with water. Chemical auxiliaries such as wetting agents, pH control agents, leveling agents, and chelating agents are then added to the bath followed by the dyes. The machine is heated from ambient to dyeing temperatures at a fixed rate (usually 3-4°F/min.) and held at the dyeing temperature for the time required to complete the dyeing. The goods being dyed are checked for proper shade, and if the shade has been attained, the dyebath is discharged to the drain. The goods are then post-scoured and/or rinsed to remove unfixed dye. The goods are removed from the machine, and the machine is refilled with water for the next load.

If the dyebath is examined before and after the dyeing cycle, two major changes have occurred: most of the dye has been removed from the bath by the yarn or fabric and the bath is hot rather than cold. Most of the auxiliary chemicals added to the bath are still present in the same condition as they were at the start of the dyeing cycle. When the dyebath is discharged to the drain, large quantities of energy, water and useful chemicals are lost. A more reasonable procedure would be to analyze the spent dyebath for the remaining dye, to reconstitute the bath to the desired strength, and to reuse it for subsequent dyeings. Reuse of dyebaths was calculated to significantly reduce the energy, water and chemical requirements in batch dyeing, as well as reduce pollution loads.

For the past several years a major research program in the School of Textile Engineering at Georgia Tech has been directed toward evaluation of the technical and economic feasibility of reconstitution and reuse of dyebaths. In previous papers on the work the laboratory equipment (2-5) of the reuse system has been described and the actual demonstration of reconstitution and reuse of dyebaths in hosiery dyeing (6-7), carpet dyeing (8) and fabric dyeing (9) have been reported. The plant experiments showed that dyebath reconstitution and reuse could reduce water use and discharge by 64% in hosiery dyeing, 57% in carpet dyeing and 45% in fabric dyeing with no reduction in quality of the dyed fabric or increase in production problems.

Dyebaths can be reused routinely for five to ten dyeings but eventually the bath must be discarded when a light color must be dyed following a very dark color. The current work was undertaken to develop a system to decolorize and reuse baths from dyeing of dark shades so that further reuse of the dyebath would be possible. Ozone and/or excited "singlet" oxygen were selected for the decolorization studies. Both of these species have been previously demonstrated to be effective in destroying the color of dyes (10).

EXPERIMENTAL PROCEDURES

The dyes and chemical dyeing auxiliaries selected for study were ones commonly used in the coloration of nylon and polyester carpet. Since all commercial dyes contain substantial quantities of additives and impurities, it was necessary to purify dye samples prior to use. Standard techniques were used for purification.

Concentrations of dyes in solution were obtained by absorption spectrophotometry (11). Standard dye solutions were prepared by dissolving 1 gram of purified dye in 1 liter of distilled water. Other concentrations for preparing absorbance versus concentration curves were made by dilution of the 1 gram per liter standard solution.

The active oxygenspecies for decolorization of dyes were produced with the apparatus shown in Figure 1.

Ozone was produced by flowing either pure oxygen or air through a 9000 volt ozonator and then diffusing the active species through a used dyebath. Singlet oxygen was similarly obtained by passing pure oxygen or air around a short wavelength lamp.

The quantities of active species produced by the various systems were obtained by filling the gas bottles with 150 ml of standard potassium iodide solution and determining the active specie as ozone by the procedure given in Standard Methods (12). Early experiments on decolorization of dyes by the various techniques showed that ozone was more effective than "singlet" oxygen. Subsequent experiments were limited to ozone decolorization.

The quantities of ozone required to decolorize each of seven dyes selected for initial study were determined quantitatively with the apparatus shown in Figure 1. In these experiments the dye solutions were placed in the first gas bottle of the bottom series and potassium iodide solution in the other five bottles. Equal flow was maintained in the three series of bottles so that the total ozone produced can be determined from the top row and the quantity of ozone required to decolorize the dye from the bottom row. Typical results for two acid dyes commonly used for dyeing nylon carpet are shown in Figure 1. In general the results showed that a quantity of ozone roughly equivalent to the weight of the dye in solution was required to decolorize acid and basic classes of dyes. Disperse dyes used to dye polyester carpet required much larger quantities of ozone as can be seen from Figure 3.

Since dyebaths are generally hot at the end of the dyeing cycle, the effect of temperature on decolorization was also explored. At 80°C,acid dyes required approximately 30% greater quantities of ozone for decolorization. Disperse dyes were more easily decolorized at elevated temperatures as shown in Figure 3. The greater solubility of disperse dyes at 80°C is probably responsible for this increased efficiency of decolorization.

In addition to dyes, spent dyebaths will have appreciable quantities of auxiliary chemicals added to control the dyeing process. These chemicals will also react with ozone and the rate of reaction compared to ozone reaction with dyes will be an important consideration in the economic evaluation of ozone decoloration and dyebath reuse.

Two typical auxiliary chemicals were selected for study. Avitone T (duPont) is an anionic surfactant used as a dispersing agent for disperse dyes. Chemcogen 12LD (Chemical Processing of Georgia) is a typical anionic type leveling agent used in acid dyeing of nylon carpets. Results of the exposure of these two auxiliary chemicals to ozone at room temperature (25°C) are shown in Figure 4.

Results of the sudy of effects of ozone on auxiliary chemicals were encouraging since they indicate that these types of compounds react more slowly with ozone than the dyes. They should, therefore, have a low ozone demand during dye decoloration and substantial quantities of the auxiliary chemicals should be recyclable in the process.

DYEING IN RECYCLED BATHS

The possible effects of ozone decolorization of waste dyebaths on the carpet dyeing process was investigated in three series of dyeing experiments.

Nylon Carpet Dyeings

Nylon carpet samples dyed with a mixture of acid and basic classes of dyes were selected for initial studies. The nylon carpet samples were prescoured to remove fiber lubricants, identification tints, etc. A 50 gram sample of the carpet was placed in a beaker and 1.5 liters of water (liquor ratio of 30:1) were added. A leveling agent, pH control agent, and three dyes, Acid Red 151, Acid Blue 40 and Basic Yellow 11 were added to the bath. The temperature was raised to 100°C at 2°C per minute and held at 100°C for fifteen (15) minutes. Acetic acid was added to adjust the pH to 4.5 and the dyeing continued for thirty (30) additional minutes. The carpet was removed from the beaker and rinsed and afterscoured.

The residual dyebath was then exposed to ozone to decolorize the remaining dyes. The dyebath was used for five (5) consecutive dyeings before being discarded. The quantities of ozone actually required for dyebath decoloration was very close to the amount calculated from the residual dye concentration and the ozone dye decoloration curves previously obtained.

The five samples of nylon carpet dyed consecutively in the same dyebath by decolorizing with ozone and reuse of the bath were evaluated for color reproducibility, stability of the color to light exposure (lightfastness), colorfastness to water exposure, and colorfastness to abrasion (crockfastness) (13). Standard exposure conditions and evaluation procedures were used to assess the quality of the dyeings in recycled baths.

Results of the color reproducibility study are shown in Table 1. Color differences between the first dyeing (in a fresh bath) and the four subsequent dyeings (in the recycled bath) were calculated using the Friele-MacAdam-Chickering equation (FMC-II) (14). In this system, one unit of color difference is a just perceptible color difference to the average observer. All color differences for the acid and basic dyed nylon were within acceptable ranges for commercial production of nylon carpets. Colorfastness of the dyeings were also acceptable.

Polyester Carpet Dyeings

Polyester carpet samples were dyed with disperse dyes in a manner similar to the nylon carpet dyeings described previously. A large piece of polyester carpet was prescoured to remove fiber lubricants, identification tints, etc. A 50 gram samples of the carpet was placed in a 5-liter beaker and 1.5 liters of water (liquor ratio of 30:1) were added. A dye dispersing agent, a pH control agent, and three dyes, Disperse Yellow 42, Disperse Red 60 and Disperse Blue 7 were added to the bath. The pH was adjusted to 5.0 with acetic acid and a dye carrier, (10% owf or 5 grams) was added. The temperature was raised to 100°C and maintained for one hour. The carpet sample was then removed from the beaker, rinsed with warm water, afterscoured, and dried at 120°F for one hour.

The used dyebath was then exposed to ozone to decolorize the residual dyes. The bath was then reconstituted to its original volume and used for the next dyeing. Five dyeings were carried out in the same bath.

As noted for the nylon carpet dyeings, the actual ozone requirements were very similar to the calculated requirements based on dye decolorization experiments carried out earlier.

The polyester carpet samples were also tested for color reproducibility and colorfastness.

Somewhat larger color differences of the order of 5 or 6 FMC II units are observed for the polyester dyeings in recycled baths. Apparently during the decolorization of waste dyebaths containing disperse dyes, oxidation by-products are formed and accumulate which can oxidize a portion of the dyes added for the subsequent dyeing. The color difference increases for each dyeing run if the decolorized dyebath is reused without being reduced (run 2-5).

In order to correct this problem a sixth run was made in the spent dyebath using a small amount of a reductant, $Na_2S_2O_3$, (sodium hydrosulfite is a common reductant used in textile operations) prior to the added dye and sample 6 is well within acceptable color difference limits. This procedure would probably be required in production use for polyester dyeings.

Colorfastness results were comparable for both the sample dyed in the initial bath and samples dyed in the recycled baths.

Combined Reconstitution and Ozone Decolorization

In the final study the combination of reconstitution and reuse of dyebaths with ozonation and continued reuse was investigated using the formulation of actual commercial dyeings. A standard dark brown dyeing was carried out using nylon carpet, followed by two dark brown dyeings. These first two reuses were accomplished by analyzing the spent dyebath for residual dye, then replenishing the bath with the required amount of dyes and chemicals and then dyeing the next sample. For the fourth dyeing, the spent dyebath was treated with active oxygen species produced by the ozonator using air until no color remained. For a rigorous test of the active species degradation, a light beige sample was dyed as the third reuse. The color difference between the third reuse and a standard light beige sample was very acceptable, being only 2.4 FMC II units (see Table 1).

CONCLUSIONS

Results of the study have led to a number of important conclusions about decolorization and reuse of dyeing wastewater.

1. Acid/basic dyes can be readily destroyed by treatment with ozone. Disperse dyes can also be destroyed but require a larger quantity of ozone.

2. Textile auxiliaries are not as rapidly destroyed as dyes by ozone. It should be possible, therefore, to destroy the color and reuse both the water and a substantial quantity of auxiliary chemicals.

3. Nylon carpet can be dyed in recycled baths that have been decolorized by ozone. Carpets dyed in recycled baths are of acceptable commercial quality.

4. Polyester carpet can be dyed acceptably in ozone decolorized baths if the bath is treated with a reductant prior to reuse.

5. Ozone decolorization can be combined with reconstitution and reuse systems to permit dyeing of lighter shades after darker shades in spent dyebaths.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support of this work by the Office of Water Research and Technology.

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Table 1. Color Reproducibility From Run to Run Ozone Decolorization

Sample		DE (FMC II Units)
Acid Dyed Nylon Std.	No. 1	-
Sample	No. 2	3.3
	No. 3	3.8
	No. 4	3.9
	No. 5	3.0
Basic Dyed Nylon Std.	No. 1	-
Sample	No. 2	3.6
	No. 3	2.8
	No. 4	3.8
	No. 5	3.7
Polyester Std.	No. 1	-
Sample	No. 2	2.3
	No. 3	2.0
	No. 4	4.9
	No. 5	6.4
	No. 6	0.3
Nylon Reuse Std.	Dk. Brown	-
	Dk. Brown	3.4
	Dk. Brown	5.8
	Lt. Beige	2.4*

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* Compared to standard light beige dyeing.

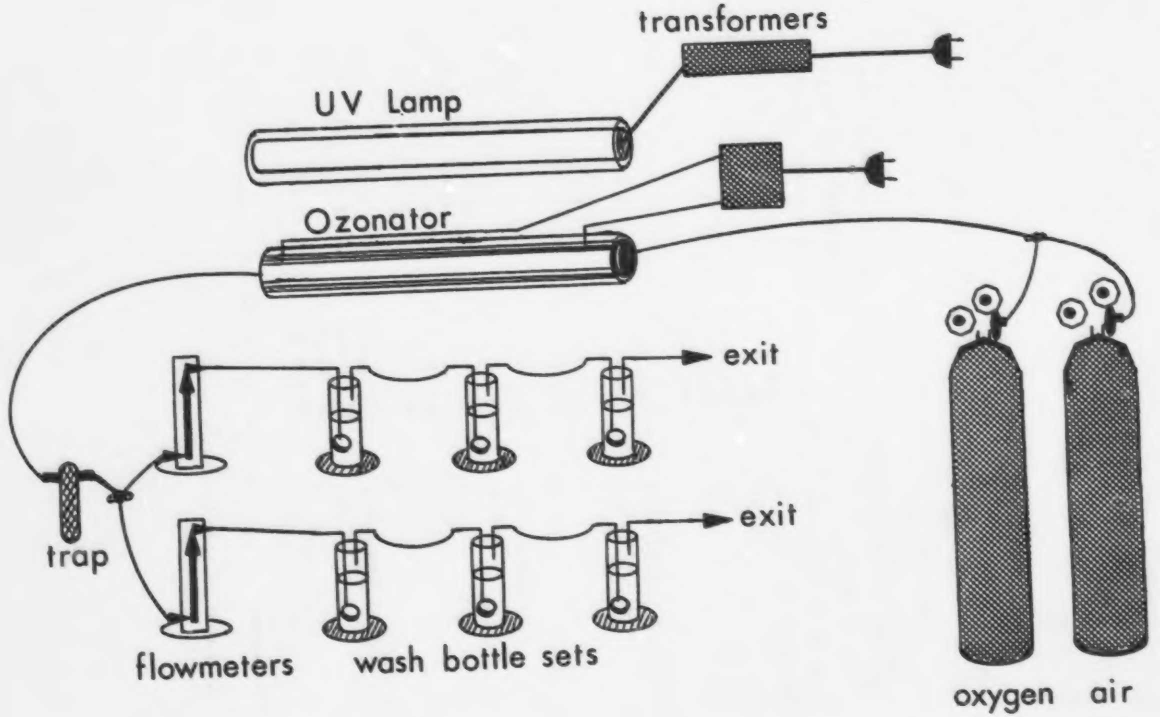
transformers
UV Lamp
Ozonator
exit
exit
trap
flowmeters
wash bottle sets
oxygen
air

Figure 1. Ozone/Singlet Oxygen Apparatus

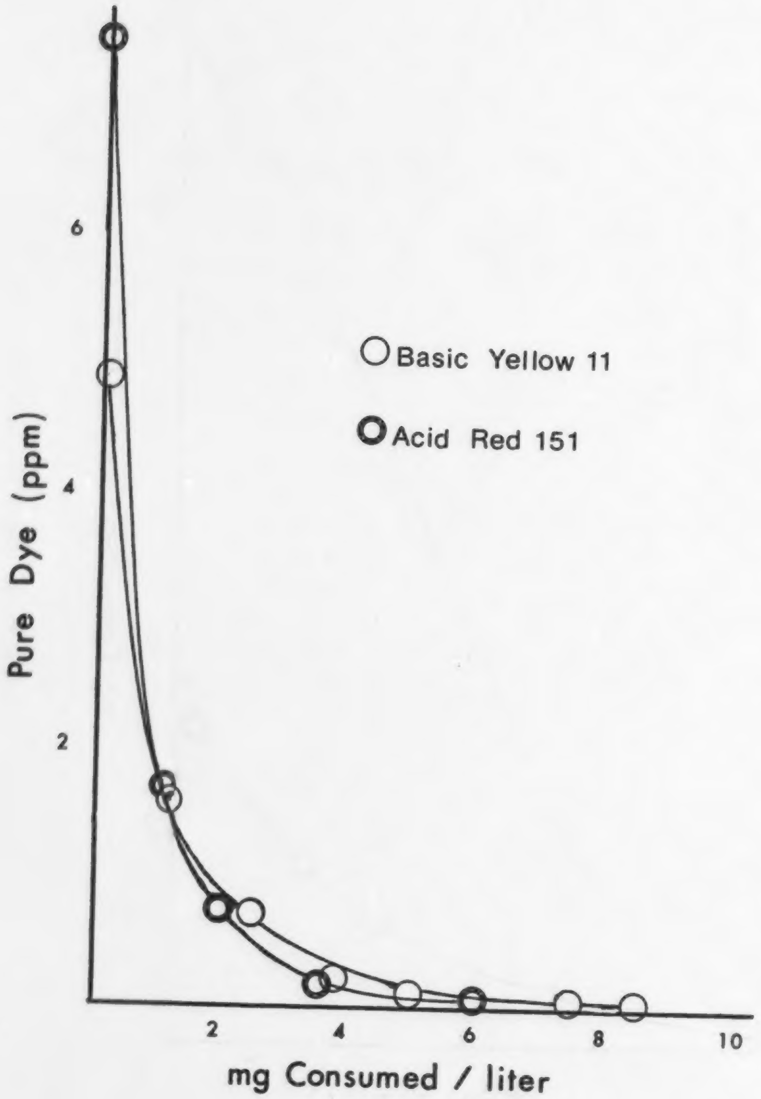

Figure 2. Dye Decolorization by Ozone.

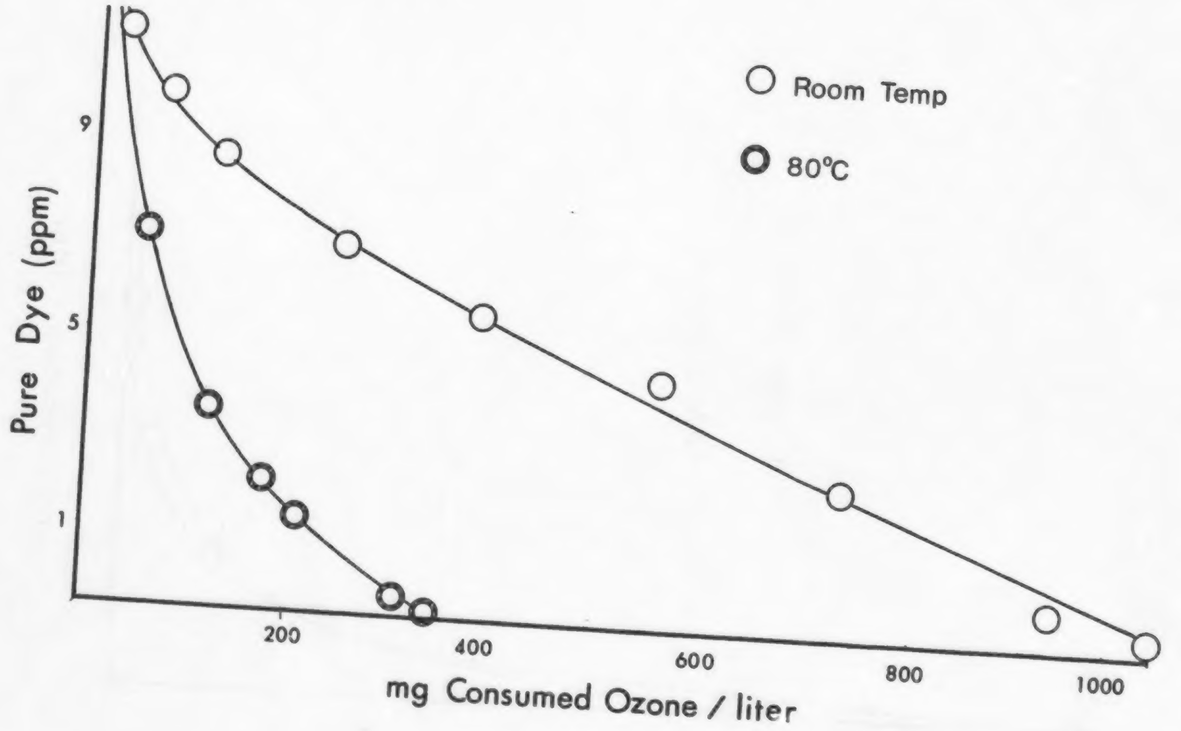

Figure 3. Ozone Decolorization of Disperse Yellow 42.

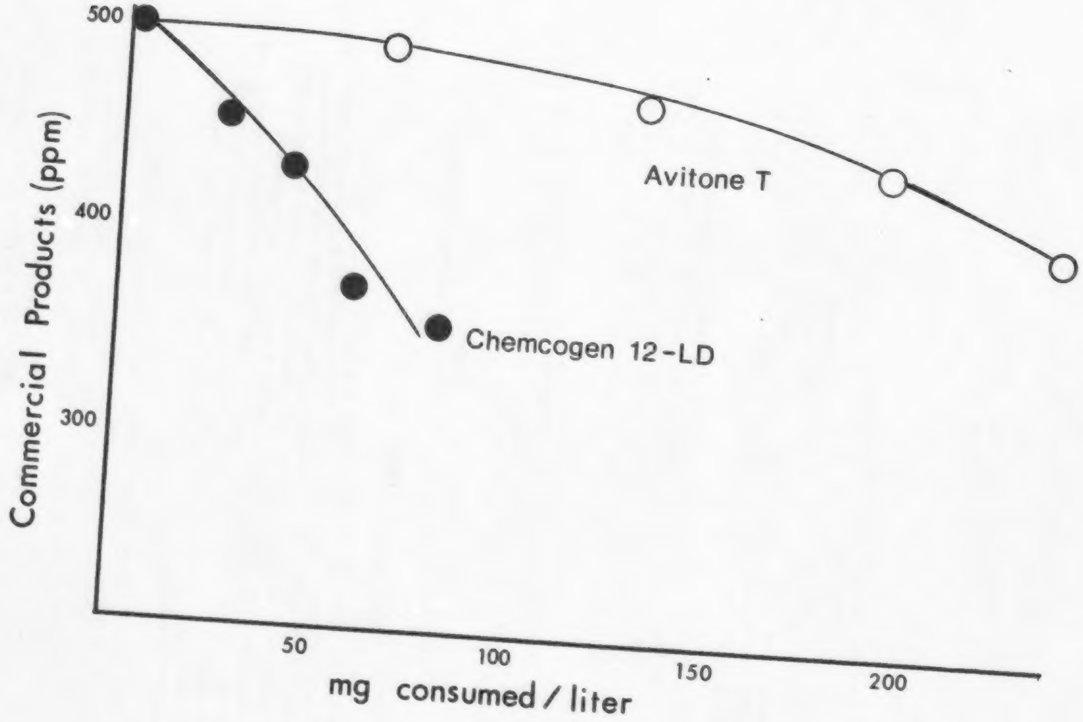

Figure 4. Ozone Oxidation of Auxiliaries

WATER REUSE AND RECOVERY IN TEXTILE FINISHING MILLS

Petr Janak
Research Worker
Research Institute of Textile
Finishing
Dvur Kralove n.L., 54428
Czechoslovakia

INTRODUCTION

Water consumption in all industrial branches has been constantly growing. At the same time it is still more evident that clean water supplies are not inexhaustible and in some areas, the water is a limiting factor of further industrial development. Also growing cost of water and legal regulations, which lead to more stringent requirements for wastewater discharging, make preconditions for economically efficient water reuse.

This process is not sufficiently spread in textile industry yet, possibly with the exception of counter current flow of water during rinsing and some infrequent cases of cooling water reuse for next operations (1). Great requirements on the quality of process water on the part of technologists make a wide-spread water reuse more difficult.

In a survey of possibilities for reduction of clean water consumption in cotton industria of Czechoslovakia, two alternatives for water reuse were checked in 1977 - 80 in full scale:

1. Direct rinsing water reuse.
2. Reuse of effluents after additional treatment.

DIRECT WATER REUSE IN PRELIMINARY FINISH

Discontinuous rope bleaching plants are being mostly replaced by continuous process. An example of technological assembly of rope bleaching plant with four saturators, four J-boxes and four washers (type Cilander) is shown in Fig. 1. Technology in use incorporates desizing, alkaline scour, hypochlorite bleaching and peroxide bleaching. Generally the hot water is fed into the first, second and fourth washer, i.e. rinsing after desizing, scouring and peroxide bleaching. Drains from every washer go into a sewer that leads to wastewater treatment plant.

Water passage through washers even after flow optimisation (2) fluctuates between 6 - 10 $m^3 .h^{-1}$, average 8 $m^3 .h^{-1}$. An example of wastewater pollution from particular washers, when bleaching cotton cloth having an average areal weight 100 $g.m^{-2}$, is shown in Table I.

As it is evident from Table I, hypochlorite and peroxide bleaching wastewater have essentially lower organic loading and lower caustic pollution than wastewater from the first two washers. Moreover the peroxide bleaching wastewater is warm. The possibility of reuse wastewater from the fourth washer in the second washer has been practically checked. This cycle has been improved by the reuse of the second washer wastewater in the first washer. Characteristic pollution parameters of reused water are given in Table II.

Although the pollution values of rinsing water after desizing and scouring are relatively high, it has been experimentally checked that water reuse had not affected the quality of goods. On the contrary, alkalinity of rinsing water fed into the washer after desizing has caused that the size in the first washer has been more effectively removed.

By the above mentioned process water savings up to 30-50% and also significant energy savings for water heating on the first and second washer may be achieved in the bleaching mill. Together with wastewater heat recovery these energy savings may represent up to 60%.

The water reuse is accompanied even by some negative phenomena. It is above all formation of incrustations, filling of pipes and drains by composites of calcium incrustations and fibre impurities. Therefore a magnetic water treatment device (type MU - CKD Dukla) has been installed into a water supply of the fourth washer. On the outflow of the first, second and fourth washer a specially adapted cylindrical screen Textima has been installed. Both equipments have proved rather effective in the reduction of incrustations quantity.

Rinsing water after repeated use is further led into the heat recovery circuit, where heat energy contained in rinsing water is used for process water heating. Objective diagram of the whole reuse and heat recovery circuit is shown in Fig. 2.

REUSE OF EFFLUENTS

50 m^3 municipal wastewater treatment plant effluents were additionally treated on a pilot scale unit by the following process (3): coagulation by alum (50 - 100 mg. l^{-1} $ALCl_3$), sand filtration, softening on ion-exchange resin in Na cycle (Fig. 3).

Characteristic pollution of effluents from municipal wastewater treatment plant, renovated water and comparison with the standard draft of process water quality is given in Table III. The contents of suspended solids were reduced on an average by 98.9%, COD by 64.0% and BOD by 87.9% (4). Dyeing tests with renovated water did not show, the same as in preceeding case, any shade differences or worsened workability.

Considering the fact that textile wastewater takes only 25% of total volume of wastewater treated in municipal wastewater treatment plant, it could be possible to achieve later nearly 100% reuse of process water. The only condition is to build up a water treatment plant with the capacity for the whole finishing mill.

CONCLUSION

The possibility of direct water reuse was verified at full-scale in a continuous rope bleaching plant. On the basis of results obtained, a scheme for water reuse and heat recovery can be designed, by which up to 50% process water savings and up to 60% heat energy savings for rinsing water heating can be achieved.

Physical-chemical wastewater treatment process (coagulation, sand filtration, softening) was checked as one of the alternatives for water additional treatment by reusing. Biologically treated municipal effluents were treated by this process to such a high degree that when reused in the dyehouse, no shade changes or colour fastness reduction has been observed.

Because of actual relatively low process water cost, methods of water reuse are not sufficiently spread in textile industry yet. At present the cost of renovated water is still rather high, but in the future when water becomes more expensive and water resources more limited, these methods will have a better prospect for wide-spread use.

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Table I - Wastewater pollution from particular washers

washer	1	2	3	4
pH	9.96	12.68	9.95	9.62
hydroxide alkalinity (mmol.l^{-1})	5.67	134	2.40	1.80
total alkalinity (mmol.l^{-1})	22.63	154	7.05	5.30
COD (mg.l^{-1})	4461	3861	598	451
conductivity (mS.cm^{-1})	1.65	26.2	27.1	8.1

Table II - Average pollution of rinsing water after reuse by method 4 - 2 - 1

waste from washer	4	2	1
pH	9.62	12.34	12.79
hydroxide alkalinity (mmol.l^{-1})	1.80	52.20	61.40
total alkalinity (mmol.l^{-1})	5.30	72.70	91.25
COD (mg.l^{-1})	451	3297	4354
suspended solids (mg.l^{-1})	8.20	85.44	112.16
conductivity(mS.cm^{-1})	8.10	8.92	9.83
total hardness (meq.l^{-1})	2.30	3.85	4.43

Table III - Renovation of biologically treated wastewater

Parameter	1	2	3
transparency (cm)	--	55	50
pH	7.54	7.90	6.5-8.0
hydroxide alkalinity ($\mathrm{mmol.l^{-1}}$)	0	0	0
total alkalinity ($\mathrm{mmol.l^{-1}}$)	5.06	--	--
suspended solids($\mathrm{mg.l^{-1}}$)	18.0	0.22	--
dissolved solids - 600°C ($\mathrm{mg.l^{-1}}$)	--	443	600
permanganate value ($\mathrm{mg.l^{-1}}$)	--	3.8	15
COD ($\mathrm{mg.l^{-1}}$)	72.5	26	--
BOD ($\mathrm{mg.l^{-1}}$)	14.3	1.7	--

1 - municipal wastewater treatment plant effluent

2 - renovated water

3 - standard draft

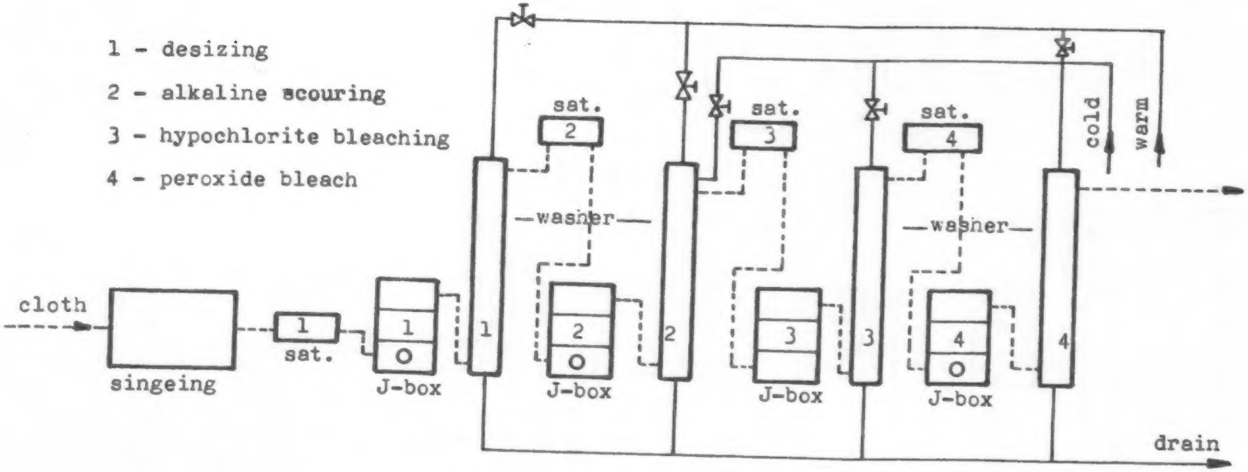
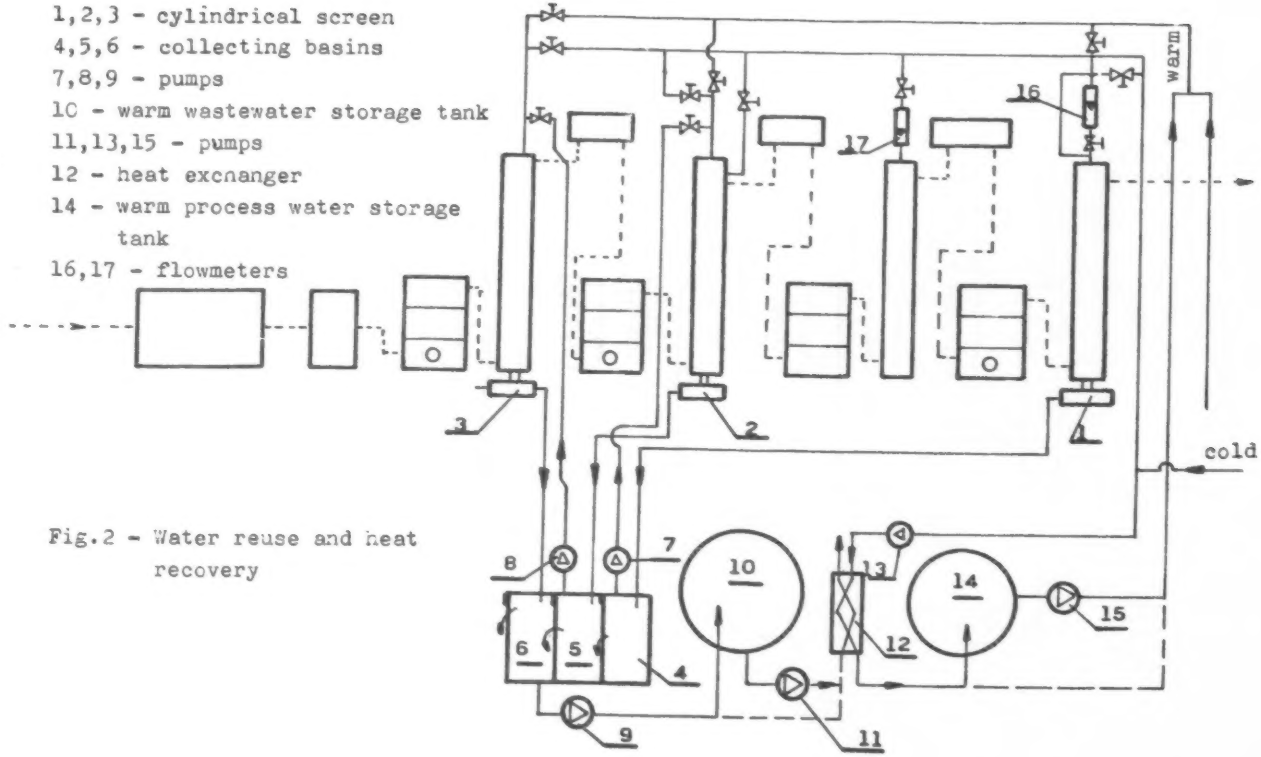
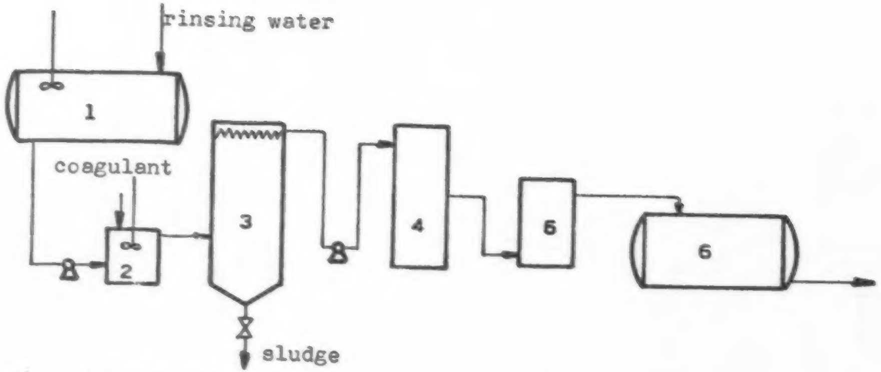

1 - desizing
2 - alkaline scouring
3 - hypochlorite bleaching
4 - peroxide bleach
cloth
singeing
1
sat.
1
J-box
1
sat.
2
—washer—
2
J-box
2
sat.
3
3
J-box
3
sat.
4
—washer—
4
J-box
4
cold
warm
drain

Fig.1 - Continuous rope bleaching plant


warm
cold
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

1,2,3 - cylindrical screen
4,5,6 - collecting basins
7,8,9 - pumps
10 - warm wastewater storage tank
11,13,15 - pumps
12 - heat exchanger
14 - warm process water storage tank
16,17 - flowmeters

Fig.2 - Water reuse and heat recovery


rinsing water
1
coagulant
2
3
sludge
4
5
6

1 - rinsing water storage tank
2 - mixing basin
3 - clarifier

4 - sand filter
5 - ion-exchange
6 - storage tank

Fig.3 - Diagram of rinsing water treatment

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WATER REUSE IN THE PULP AND PAPER INDUSTRY IN CALIFORNIA

Sandra Gay Yulke,
Scientist
Dr. James T. O'Rourke
President, Industrial Division
Camp Dresser & McKee Inc.
One Center Plaza
Boston, Massachusetts 02108

Dr. Takashi Asano
Water Reclamation Specialist
Office of Water Recycling
California State Water Resources Control Board
P.O. Box 100
Sacramento, CA 95801

INTRODUCTION

California has long been the leading state in the respect to water reuse. Historically, in order to develop its population and industrial centers, located in water-short areas, the state developed a complex water supply and distribution system. But even this system cannot meet all the water demands in the state, and further, the solution to California's chronic water problem does not necessarily lie in the development of additional surface or groundwater sources. The serious drought that occurred in 1977 showed that this is indeed the case, and that water conservation is a key to ensuring adequate supplies. One aspect of conservation is water reuse or recycling and the Office of Water Recycling (OWR) was established to consolidate and expedite water recycling efforts. The state, through OWR, has therefore placed great emphasis on the development of systems for water reclamation and reuse, particularly for industries that are large, easily identifiable users.

The pulp and paper industry is second only to agriculture as the largest industrial user of water in California[1]. Because the industry is responsible for one out of every six gallons of industrial water used, it is a primary candidate for water conservation by reuse, recycling or reclamation. The industry will realize genuine economic savings from conservation efforts as costs of water supply continue to rise and approach "free market" values. Additional impetus toward reuse, recycling and reclamation will come from the increasing wastewater-disposal costs faced by pulp and paper manufacturers.

For the purposes of this discussion, the three methods of water conservation under consideration are defined as follows:

Reuse. The use within the pulp and/or paper mill of treated wastewater from a municipal plant or other outside source.

Recycle. The reuse within the mill of mill process water, with or without treatment.

Reclamation. The use of mill effluent, either treated or untreated, for other, unrelated industrial or commercial purposes, such as irrigation of crops or landscape.

The Pulp and Paper Industry in California

There are approximately 50 pulp and paper mills and manufacturing facilities in the State of California[2,3], located mostly along the Sacramento River and around San Francisco Bay in the north, and around the Los Angeles basin in the south. Figure 1 shows the type and location of these mills (paperboard mills are included with paper mills).

The manufacture of pulp and paper involves the use of water at almost every process step, so it depends absolutely on a readily available, large supply of water. Water is used for cooling and grinding wood chips to make pulp, repeated washings of pulp, and transporting the fibers through the bleaching, refinery and sheet-forming processes. Water is also needed for boiler feed and for cooling.

Over the years, the pulp and paper industry has made considerable progress in reducing its consumption of freshwater. When paper was first made, by hand, between 300,000 and 400,000 gallons of water were required to produce one metric ton of rag pulp and paper[4]. By the beginning of the 20th century, when some reuse of process water on the paper machine had begun, this amount had been cut in half. In the 1930s, water consumption typically was 25,000 to 80,000 gallons per metric ton (gpt) of paper (86 to 275 m^3/ton). Current environmental and energy considerations have helped to lower consumption to the 3,000 to 25,000 gpt (11 to 86 m^3/ton) range.

Table 1 shows that there is wide variation in the amount of process water per ton of product used by California mills of different types (product is measured on a dry weight basis). This variation in use of process water reflects the amount of recycling of process water within a mill, which is affected by the quality of paper which the mill produces. The higher the quality of paper produced, the higher the quality of water required. Thus, paper quality determines the amount of treatment necessary for recycling within the mill or the degree of treatment necessary for municipal effluent to be acceptable for reuse within the mill. The degree of treatment required to meet quality requirements, in turn, determines the cost of the water.

Factors Affecting Reuse

Quality and cost are the two factors which determine the extent to which a paper mill will reuse, recycle or reclaim water. If treated municipal effluent is lower in cost than any other source of available process water, it makes economic sense for a mill to use it. But, if its quality is inconsistent or not good enough to meet the plant's needs, it will not be purchased regardless of its cost.

The same quality versus cost tradeoff must be made for internal mill recycling. It is economical to treat used mill process water as long as the value of the recovered material (solids, heat and the water itself) is greater than the treatment costs. When considering using plant effluent for agricultural reuse, similar issues of cost arise. Present regulations stipulate lower levels of treatment for plant effluent that is to be applied to land than for effluent that is to be discharged directly to a watercourse or to a municipal treatment facility. As long as treatment costs for land application remain lower than for stream discharge or disposal to a municipal wastewater treatment plant (WWTP), reclamation will be an economically viable alternative in the pulp and paper industry.

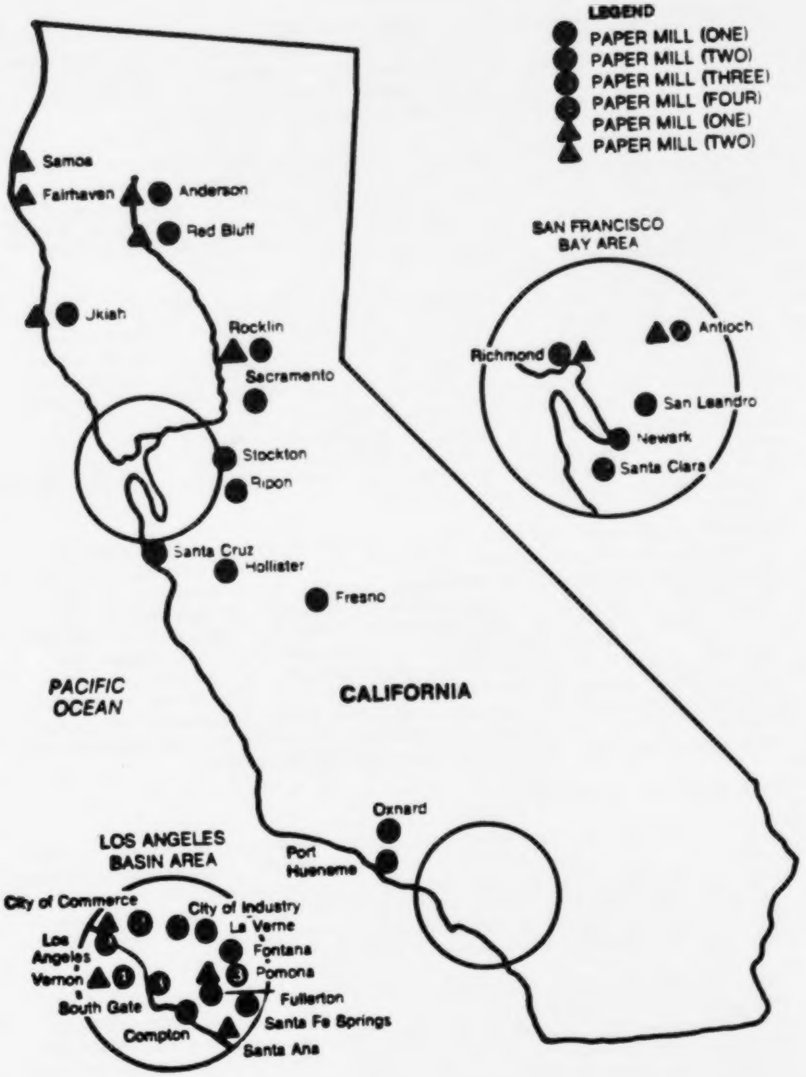
LEGEND
PAPER MILL (ONE)
PAPER MILL (TWO)
PAPER MILL (THREE)
PAPER MILL (FOUR)
PAPER MILL (ONE)
PAPER MILL (TWO)
Samoa
Fairhaven
Anderson
Red Bluff
Ukiah
Rocklin
Sacramento
Stockton
Ripon
Santa Cruz
Hollister
Fresno
SAN FRANCISCO
BAY AREA
Antioch
Richmond
San Leandro
Newark
Santa Clara
PACIFIC
OCEAN
CALIFORNIA
Oxnard
Port
Hueneme
LOS ANGELES
BASIN AREA
City of Commerce
City of Industry
La Verne
Los
Angeles
Fontana
Vernon
Pomona
South Gate
Fullerton
Compton
Santa Fe Springs
Santa Ana
1
3

FIGURE 1
GEOGRAPHIC DISTRIBUTION OF PULP AND PAPER MILLS IN CALIFORNIA

(after 2, 3, 4.)

TABLE 1
WATER USAGE IN CALIFORNIA PULP & PAPER MILLS
(Gallons Per Day Per Ton)

	Felt and Roofing	Paperboards	Tissue and Toweling	Bleached Kraft	Fine Paper
Range	770-4,400	700-9,000	6,200-30,000	9,700-37,000	5,600-21,000
Average	2,000	3,400	15,000	19,000	14,500

Total Usage: 120,000,000 gpd.

We therefore have the current situation: in general, pulp and paper mills are able to obtain freshwater supplies at the necessary levels and at a price equal to or less than that of treated municipal effluent. At present, mill operators are more concerned about the cost of wastewater treatment than water supply. Agricultural reclamation and internal plant reuse have been instituted primarily to reduce wastewater treatment costs, not to reduce overall water consumption.

Position of Industry with Respect to Water Reuse

A survey conducted as part of this study found that in principal the pulp and paper mills operators were interested in water reuse provided that it would not increase their costs or have a detrimental effect on their product. This response summarizes the typical industrial goal: to make the best product possible for the lowest cost. Several of the mill operators indicated that they were in the process of making changes to increase internal water reuse.

Water is the inherent medium of the industry and directly affects the quality of the resulting products. Impurities, both suspended and dissolved, present in the water and the temperature of the water can affect both the product and equipment. Table 2, taken from a survey performed by the National Council of the Paper Industry for Air & Stream Improvement (NCASI), lists a number of potential problems. More extensive water quality data, collected by NCASI in a plant survey, can be found in their publications.[5]

Water Quality Considerations

Basically, the "brown" grades of paper are the most tolerant of recycled water. These include roofing paper (for asphalt or tar-saturated papers, nearly 100 percent in-mill recycle is possible), linerboard, low-brightness carton board, packaging and insulating board. The next most tolerant are the low-brightness "white" grades such as newsprint, which can be produced with less than 3,000 gallons of makeup water per ton, and paper towelling and bathroom tissue, followed by facial tissue, table napkins and "whitetowels" for kitchen use.

The quality of high whiteness (brightness) grades, the "fine papers", is much more sensitive to water quality[6]. Impurities in water, particularly certain metal ions and color bodies, can cause the paper produced to change color rapidly with age, a phenomenon termed "color reversion".

Table 3 is a summary of water quality specifications for pulp and paper products published by the California State Water Resources Control Board. As the table indicates, water quality requirements can vary by as much as a factor of 20, as in the case of color. It is therefore not possible to make hard and fast determinations on a particular water's suitability for reuse. Water unsuitable for bleached kraft manufacture may be useable for paperboard; its usefulness must be determined empirically. Pilot plant results may even show that, with some treatment, fine paper manufacture would be feasible after all.

An additional concern of mill operators regarding reclaimed water is the guarantee of a consistent supply with respect to both quality and quantity. Changes in either can cause production to diminish or cease altogether. The inability, particularly of a municipal wastewater treatment facility, to make such guarantees necessitates the mainten-

TABLE 2
POTENTIAL PROBLEMS ENCOUNTERED IN WATER REUSE IN PAPER AND BOARD MANUFACTURE

Dissolved Solids Buildup	Suspended Solids Buildup	Thermal Energy Buildup
Slime	Dirt	Temperature
Foam	Erosion	Sizing Problems
Pitch	Fines	Machine Room Temperature
Corrosion	Felt Plugging	Reduced Vacuum Pump Capacity
Sizing	Wire Plugging	
Product Mottle	Wire Life	
Color	Felt Life	
pH Control	Reduced Drainage Rate	
Precipitation	Shower Plugging	
Scale		
Odor		

TABLE 3
SUMMARY OF SPECIFICATIONS FOR PROCESS WATER QUALITY FOR THE MANUFACTURE OF VARIOUS PAPERS*

Parameter	Concentration, mg/l				
	Groundwood Paper	Soda and Sulfate Pulps	Kraft Paper		Fine Paper
			Bleached	Unbleached	
Turbidity as SiO_2	50*	25*	40	100	10
Color in platinum units	30	5	25	100	5
Total hardness as $CaCO_3$	200	100	100	200	100
Calcium hardness as $CaCO_3$	--	50	--	--	50
Magnesium hardness as $CaCO_3$	--	50	--	--	--
Alkalinity to methyl orange as $CaCO_3$	150	75	75	150	75
Iron	0.3	0.1	0.2	1.0	0.1
Manganese	0.1	0.05	0.1	0.5	0.05
Silica as soluble SiO_2	50	20	50	100	20
Total dissolved solids	500	250	300	500	200
Free carbon dioxide as CO_2	10	10	10	10	10
Chlorides	75	75	200	200	--
Residual chlorine	--	--	--	--	2.0

*Materials causing turbidity must not be gritty.

#McKee, J.E. and H.W. Wolf, "Water Quality Criteria," California State Water Quality Control Board, 1963.

+after "Water Reuse and Recycling - Vol. 1, Evaluation of Needs and Potential," U.S. Department of the Interior, Office of Water Research and Technology, April 1979, p 100 (OWRT/RU-79/1).

ance of alternative, backup supplies. This, in turn, is an additional cost to be figured into the overall economic assessment of water reuse for a particular mill.

Three Successful Cases

In spite of the inherent difficulties discussed above, water reuse of all three of the types previously described is being successfully practiced in California. The experience to date of a number of mills is described in the three cases which follow. While many mills throughout the country practice internal recycling to some degree, there are few mills elsewhere which practice either reuse of municipal effluent or reclaim their own effluent through land application.

Case 1: Reuse of Municipal Effluent

The Garden State Paper Company in Pomona, which manufactures newsprint, is currently the only mill in the United States which practices this type of reuse (South Africa has pioneered reuse of this type in the pulp and paper industry and it is ongoing in several mills there.) The City of Pomona has been reusing its wastewater treatment plant effluent since 1926, selling it for pasture and crop irrigation. The plant is currently a tertiary treatment facility; for much of the year its effluent is the only flow in a stream used for public recreation. During the most recent expansion and upgrading of the facility, the city ascertained that if it could meet somewhat higher standards, particularly with respect to color, new customers, including the local paper mills, might be found.

Water from the Pomona plant achieves the following levels of quality:

SS	2.1 mg/l
BOD_5	4 mg/l
Coliforms	2 # MPN/100 ml
Residual Cl_2	4.0 mg/l (chlorinated effluent used for reuse) 1.0 mg/l (dechlorinated)
Turbidity	1.4 NTU
Color	7 color units

Garden State uses this reclaimed water as its primary water supply, drawing it from the city's reclaimed-water distribution system.

Use of reclaimed water by Garden State Paper Company and others has eased the demand on the city's domestic water system. The flow at the Pomona Water Reclamation Plant is about 9 mgd, and the city hopes to sell all of it for reclamation. Sales data for the past year and a half are presented in Table 4. The table shows that Garden State buys approximately half of the plant's effluent on a steady basis; it is, in fact, the largest customer.

The reclaimed-water supply system at Garden State has been operating for more than a year with few problems. There have been minor water-quality problems, but, for the most part, plant personnel seem satisfied with the operation. The City of Pomona has helped Garden State overcome any operation and maintenance problems associated with the use of the effluent.

The primary water quality concerns at the Garden State Paper Company have been color and biological growth. Since Garden State is strictly a newsprint production mill, color is not as important as it is at the

TABLE 4
PRODUCTION AND REUSEOF RECLAIMED WATER
POMONA WATER RECLAMATION PLANT
(plant records)

Year	Month	Total Plant Production of Reclaimed Water (MGD)	Portion of Reclaimed Water that is Reused: Total (MGD)	Portion of Reclaimed Water that is Reused: By Garden State Paper Co. (MGD)	%
1979	Oct	7.48	3.38	1.77	52
	Nov	7.32	3.16	2.30	73
	Dec	7.56	3.53	2.11	60
1980	Jan	8.08	2.84	2.73	96*
	Feb	8.85	2.79	2.75	99*
	Mar	8.56	2.85	2.75	96*
	Apr	8.86	4.03	2.70	67
	May	8.44	3.45	2.70	78
	Jun	9.17	4.22	2.77	66
	Jul	9.26	4.67	2.35	50
	Aug	8.71	5.67	2.53	45
	Sept	8.94	5.49	2.70	49
	Oct	9.88	4.82	2.76	57
	Nov	10.19	4.06	2.67	66
	Dec	10.26	3.63	1.97	54
1981	Jan	10.17	4.30	2.91	68

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*These high percentages reflect the fact that during the winter, the rainy season, treated effluent is not purchased for irrigation. Though in the dry months, California State Polytechnic University and Bonnelli Park of L.A. County are major purchasers, Garden State, year-around, purchases at least half of all the treated effluent. Industrial reuse thus provides large, steady consumers. Should Simpson come on-line, at more than 1 mgd, pulp and paper manufacturers would account for more than a constant 50%.

nearby fine paper mill, run by the Simpson Paper Company. Nevertheless, it is still enough of a concern to be continuously monitored. Garden State Paper Company has experienced minor bacterial growth problems attributable to the use of the wastewater effluent. The mill had been extracting water from the Pomona treatment plant after it had been dechlorinated. Apparently, masses of filamentous and zoogleal bacteria were growing after the dechlorination step. Once mill water was diverted directly from the chlorine contact chamber, the 3-ppm chlorine residual eliminated the growth problem. Mill personnel are now monitoring the chlorine level to be certain it will not cause corrosion problems.

Another paper mill in Pomona is currently considering purchasing treated effluent. The Simpson Paper Company, located near the Garden State Paper Company, is one of the most water-efficient mills in the nation, with an average water use of about 6,200 gallons/ton of product (this compares with more than 10,000 gallons/ton for some other mills with similar equipment). Figure 2 is a schematic of the water circulation at the mill, showing typical pulp and paper mill water flow. The Simpson mill, unlike the Garden State mill, produces top-grade paper products such as typing and reproduction paper. The Simpson Paper Company has been considering the use of reclaimed water from the PWRP, and for the past four years its officers have discussed this with the city. The city could supply the Company with reclaimed water almost immediately because the reclaimed water line extends to a point near the mill. The primary concern is that the water will cause quality-related problems in the production of the fine paper.

Approximately 35 percent of the present water use at the Simpson mill comes from the company's own well. Even though this would appear to be an economical source of water, the well is reaching the end of its useful life and will soon need rehabilitation or replacement. Maintenance problems are already being experienced at the well, and it is expected that these will worsen. The City of Pomona is ready to supply the Simpson mill with reclaimed water at about 60 percent of the domestic water cost. Therefore, there is enough incentive for Simpson to give this proposal serious consideration. In 1980, they conducted a pilot plant program, ozonating the effluent. At that time, though the test showed use of the effluent to be technically feasible, it was felt that the cost was "prohibitive". But by early 1981, Simpson mill engineers were recommending more in-depth studies be made, and prospects for water reuse at the mill are improving.

Case 2: Internal Mill Recycle

The recycling of process water within the mill has been the major form of water reuse in the pulp and paper industry, both nationally and within California. This has been the most attractive option for four reasons: lower freshwater use and cost, greater solids recovery, greater heat recovery and reduced effluent volume and cost. In addition, inplant recycle is completely within the control of the mill.

In-plant mill recycle is practiced up to the point that the cost of treating the water for recycle, taking into account the solids and energy saved, is greater than the cost of final effluent treatment and freshwater purchase. This "break-even" point occurs at different levels in different mills, and it varies widely, depending upon the product of the mill. (Freshwater savings and effluent flow and load reductions become particularly significant when incremental increases in production produce additional effluent to be accommodated in existing wastewater treatment facilities.)

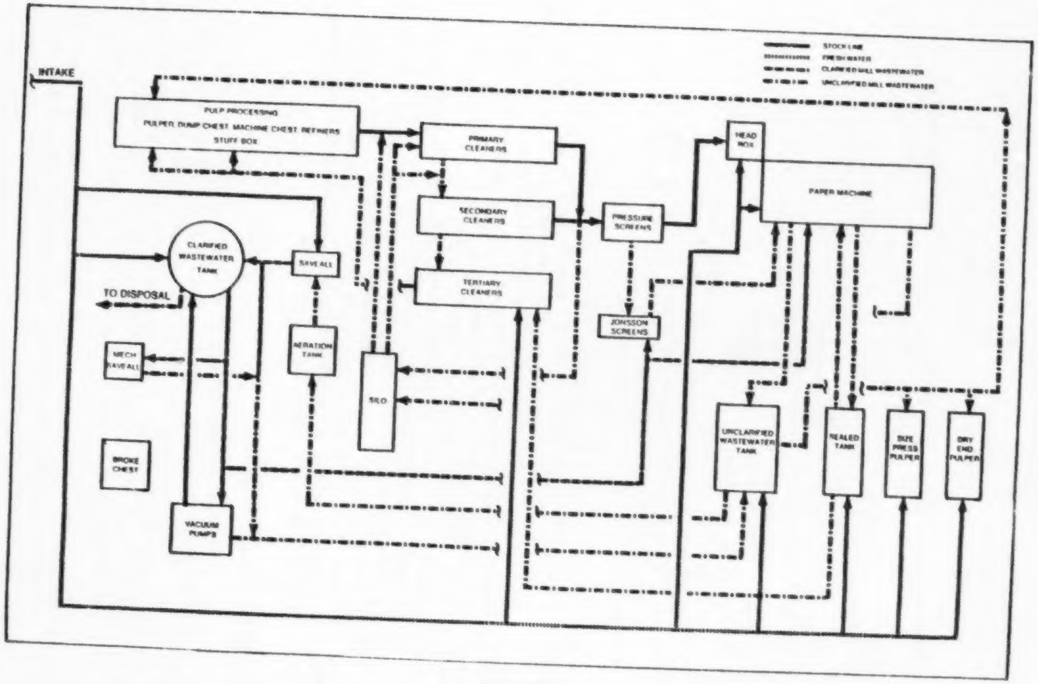

STOCK LINE
FRESH WATER
CLARIFIED MILL WASTEWATER
UNCLARIFIED MILL WASTEWATER
INTAKE
PULP PROCESSING
PULPER, DUMP CHEST, MACHINE CHEST, REFINERS
STUFF BOX
PRIMARY CLEANERS
SECONDARY CLEANERS
TERTIARY CLEANERS
PRESSURE SCREENS
JONSSON SCREENS
HEAD BOX
PAPER MACHINE
CLARIFIED WASTEWATER TANK
SAVEALL
TO DISPOSAL
AERATION TANK
SILO
MECH SAVEALL
BROKE CHEST
VACUUM PUMPS
UNCLARIFIED WASTEWATER TANK
SEALED TANK
SIZE PRESS PULPER
DRY END PULPER

FIGURE 2
SIMPSON-POMONA WATER CIRCULATION
(taken from plant records)

The paper machine is the heart of a mill, and therefore the major water user. The major conservation of water in the paper machine is accomplished by closing the various whitewater loops on the machine and recycling the vacuum pump seal waters. The whitewaters include those from a variety of sources within the paper machine including: the machine pit, wire pit, tray, flatbox, press section, couch pit, felt pit and vacuum pump (see Figure 2).

The specific amounts and characteristics of water from each of these sources will vary from mill to mill. Paper machine shower water is one of the major water uses in the paper-making process, and the reuse of treated whitewater for machine showering is possible only if there is effective suspended-solids separation. The key element, therefore, in the recycle of whitewater is the saveall, a solids/liquid separation device. Savealls may use any of the following unit processes: filtration, thickening, clarification, screening, straining and flotation. These processes may also be employed in external treatment devices such as wastewater clarifiers and mixed-media filters.

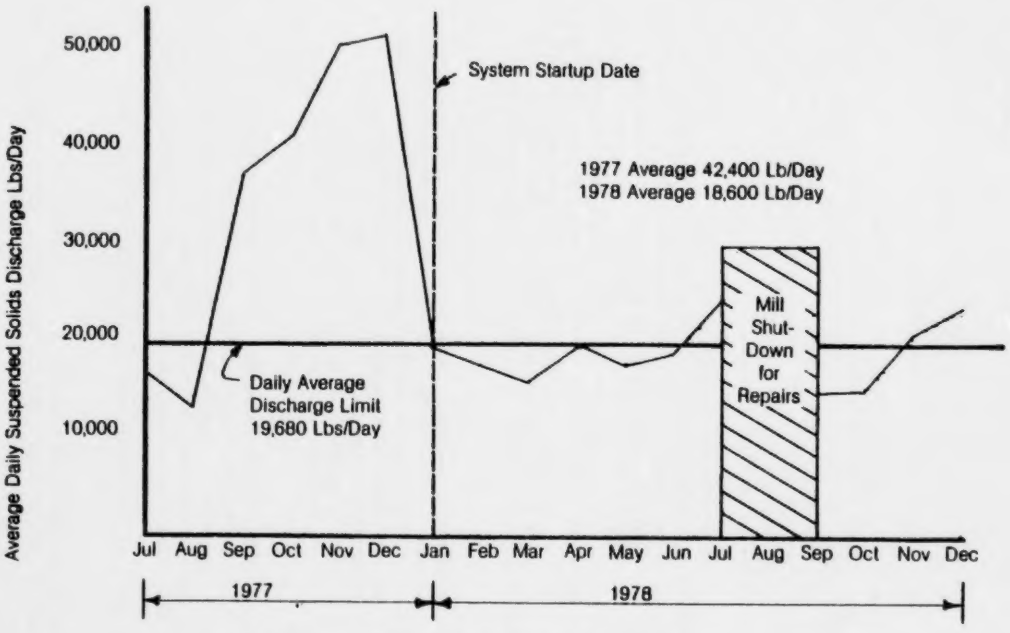
Saveall operations within a mill, while the most effective step in water recycle, may not be entirely effective or trouble-free. A saveall alone should be able to reduce the suspended solids in whitewater from a range of 1,000 to 5,000 ppm to below 250 ppm. However, additional whitewater treatment equipment, either before or after the saveall, is usually needed to provide whitewater of a consistently acceptable quality for reuse in machine showers.

An example of successful in-plant recycle is provided by the Crown Simpson Pulp Corporation's bleached kraft pulp mill in Fairhaven, California. The mill was unable, using their existing wastewater treatment system, to meet the suspended-solids discharge limitations set by the Regional Water Quality Control Board (RWQCB). The mill, which produces 600 air-dried (a.d.) tons per day (tpd) using approximately 22 mgd of water, was discharging 50,000 pounds of solid/day per (lb/day) (85 lb/day per a.d. ton) into the Pacific Ocean. The new requirements set by the RWQCB allowed 31 lb/day per a.d. ton (average) and 58 lb/day per a.d. ton (maximum). Therefore, a significant reduction was necessary.

The pulp company examined a number of ways to accomplish this change. Preliminary capital cost estimates for conventional primary treatment came to approximately $3.5 million and $2.2 million for internal changes; in addition, it was projected that annual operating costs would be higher with the conventional treatment[7]. After making this cost comparison, they decided that internal process revisions would be the most economical way to solve their environmental problems. In 1977, these changes were made.

The process changes reduced the suspended solids in the effluent by 65 percent, from 50,000 lb/day to 18,600 lb/day, within the limit specified by the RWQCB (as shown in Figure 3). While solids reduction was the goal of the process changes, there was an added dividend - water conservation. The plant's water consumption dropped 15 percent, from 22 to 19 mgd. This was particularly significant when the system was implemented in 1977, as California was in the midst of a critical drought.

The total estimated solids reduction was 33,385 lb/day; the solids reduction required was 30,980 lb/day. The filter system installation affects solids recovery and kiln operation, primarily, and is of little import-



AVERAGE DAILY SUSPENDED SOLIDS DISCHARGES

FIGURE 3
AVERAGE DAILY SUSPENDED SOLIDS DISCHARGE
AT CROWN SIMPSON

ance to water recycle. This is also true of the reject recovery system, which accounts for more than half of the suspended-solids removal. The estimated capital investment of $321,000 in that system was projected to effect annual savings of $140,000 in operations costs. But the most significant savings due to the new systems is the $548,000 in annual fiber savings; as has been true elsewhere, fiber savings are the impetus for water recycle.

Case 3: Reclamation of Mill Effluent

As the two mills described below demonstrate, this particular form of water reuse is practiced in order to reduce wastewater treatment costs, not for water reuse per se. There are a number of mills in other states (Maryland, Ohio, Michigan, Wisconsin, New Jersey, and Louisiana) which dispose of their effluent by land application, often for the irrigation of crops.

Both mills in California practicing this method are fine paper mills owned by the Simpson Paper Company. The Shasta mill, near Anderson, which produces 585 tpd, discharges to the Sacramento River, a spawning ground for anadromous fish. It therefore has to meet extremely strict discharge standards. It does this by irrigating approximately 400 acres of land it owns along the river. The high permeability soil present allows for rapid infiltration of the river bed while removing BOD and color. Oats, wheat, and grains are grown on the land, which in the first 13 months of operation, received a total of 1.03 billion gallons of effluent.

The second mill, at Ripon, produces 90 tpd, and discharges into the Stanislaus River, another water-quality limited stream. At this site, two cash crops, walnuts and a "green crop" are grown by a farmer who rents the land from Simpson. During the winter (wet) season, the effluent is disposed of on two designated disposal areas, 15 acres and 19 acres in size, respectively. During the summer, the effluent is spread on the 60-acre area of walnut orchards surrounding the mill's northern side and on the 15-acre parcel used for green crops such as alfafa and corn. Figure 4 is a site plan.

This method of disposal had been successful at both sites. The main problem encountered has been the dispolacment of calcium and magnesium in the soil by sodium from the effluent. The addition of gypsum or dolomitic limestone will correct this condition.

Discussion

These cases raise a number of issues and illustrate one particularly important point: technology is not the determining factor with respect to water reuse in the pulp and paper industry in California. Economic considerations are the most important factor and they are, in turn, a function of the legal/institutional situation.

Water and wastewater costs have risen dramatically. As shown in Figure 5, they have more than doubled over the past ten years. These increasing costs, particularly for wastewater treatment, have been the prime motivation for water recycle and reclamation. Internal plant recycle is the most popular method of water conservation because it has the added economic benefit of reducing fiber loss. Even in California, where water supplies are limited and not all potential users can be accommodated, water is still not expensive enough for its price alone to provide impetus for water conservation by reuse.

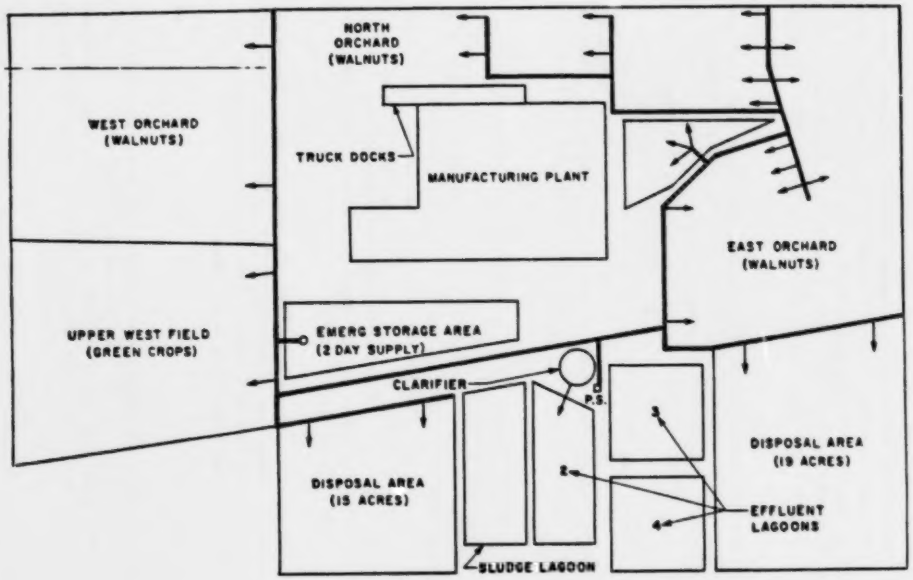

NORTH ORCHARD (WALNUTS)
WEST ORCHARD (WALNUTS)
TRUCK DOCKS
MANUFACTURING PLANT
EAST ORCHARD (WALNUTS)
UPPER WEST FIELD (GREEN CROPS)
EMERG STORAGE AREA (2 DAY SUPPLY)
CLARIFIER
P.S.
3
2
4
DISPOSAL AREA (19 ACRES)
DISPOSAL AREA (15 ACRES)
EFFLUENT LAGOONS
SLUDGE LAGOON

FIGURE 4
DISPOSAL SYSTEM AT
SIMPSON MILL AT RIPON

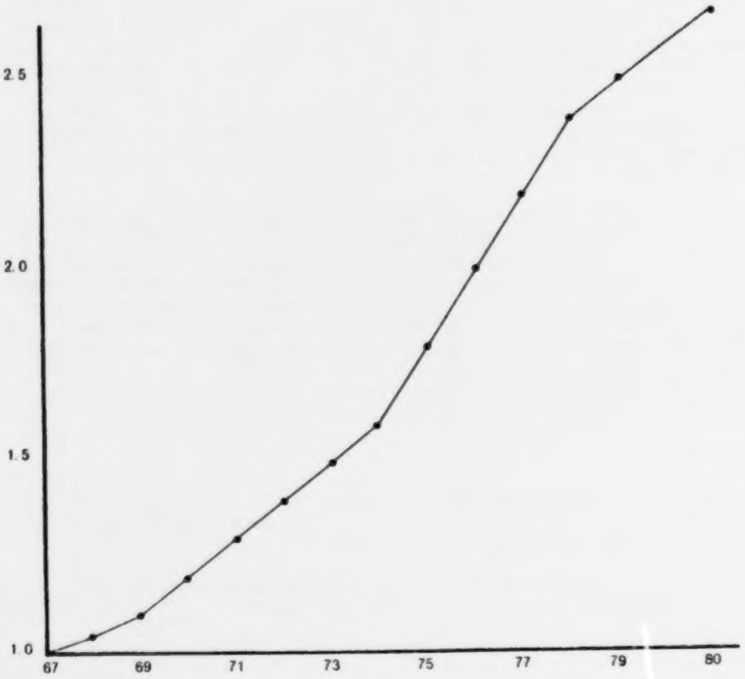


FIGURE 5
CONSUMER PRICE INDEX
WATER AND SEWAGE COSTS
(1967 = 1.00)
DEPARTMENT OF LABOR

Generally, a limited water supply is reflected in high water costs. This is not the case in California because water (and wastewater) prices are controlled; they are not allowed to reach a "fair", free-market value. Nor is pricing controlled by a single agency. As California has developed, population has centered in water-short areas, and local, state and federal agencies have all worked, usually not in concert, to bring water to those areas. Table 5 lists the agencies which are involved in water management decisions such as those associated with reuse. The complex interactions of these agencies have resulted in subsidized water costs low enough that using freshwater is cheaper than reuse, even though the actual cost of the reuse water is less, as shown in Table 6.

This is one of the more straightforward manipulations of the legal/institutional influence on water reuse. Water law in California is of both the appropriative and riparian types. Under certain aspects of the appropriative doctrine, one only maintains one's right to use water by doing so; replacing freshwater use by renewed supplies could cause the reuser to lose some of its original allotments. An additional complication comes from another set of statutes, known as "anti-paralleling". In essence, the laws protect water purveyors from competition, such as reclaimed wastewater purveyors, in order to protect the revenues water purveyors need to pay off their long-term debts.

Conclusions

The most widely practiced method of conservation in the pulp and paper industry continues to be in-plant reuse. The two primary reasons for this are economic and legal/institutional in nature:

1. The practice reduces costs, both for water purchase and wastewater treatment, to the mill operator.

2. It is totally controllable by the operator.

In the case of the pulp and paper industry in California, the gap between existing and potential reuse is not caused by a lack of technical know-how -- but rather by economic and institutional conditions at individual facilities.

Perhaps the example of two contrasting cases in the California pulp and paper industry would best illustrate the interactions of these factors.

The Santa Clara Valley Water District has investigated the use of wastewater for industrial purposes, among other uses. One major water user in the City of Santa Clara is the California Paper Board Corporation. The corporation has indicated a willingness to use reclaimed wastewater as a source of water if the operating costs are acceptable; in addition, as is the case for most industries, the corporation would like to achieve payback over a period of one to two years for any process changes that reuse of treated effluent may require.

Currently, California Paper Board draws the majority of its water supply from its own wells, with only 30 to 40 percent of its current water needs supplied by the City of Santa Clara The City of Santa Clara does not predict a water-supply problem or a major increase in water rates in the future. As a consequence, the city, although interested in wastewater reuse, is not faced with circumstances that encourage reuse, and the California Paper Board Corporation is less concerned about water supply than it is about effluent discharge, which is becoming

TABLE 5
AGENCIES CONTROLLING WATER RESOURCES MANAGEMENT IN CALIFORNIA

Federal	State	Local
President (Executive Orders)	Governor (Executive Orders)	Irrigation District
Congress (PL 92-500, etc.)	Legislature (Chapter 813; RWQCB)	Sanitary District
Department of the Interior (Office of Water Research & Technology) (OWRT)	Regional Water Quality Control Board (RWQCB)	Water District
Water and Power Resources Service (Formerly the Bureau of Reclamation)	Water Resources Control Board (WRCB)	Water & Power Department
Department of Agriculture (Farmers Home Administration)	Office of Water Recycling	
Environmental Protection Agency (Water & Wastewater Regulations) NPDES System	Department of Public Health	
Army Corps of Engineers (Flood Control, Dam Construction, Navigable Waters)	Department of Water Resources	
Department of Energy	Energy Commission	
	Resources Agency	

TABLE 6
COST OF FUTURE WATER SUPPLY ALTERNATIVES FOR ORANGE COUNTY WATER DISTRICT

Alternative Water Supply	Present Cost $/mil gal	Actual Cost* $/mil gal	Energy kwh/1000 gal	TDS mg/1
Reclaimed Water				
1. Lime/Reverse osmosis treated	780	760	8.5	50
2. Present blend of Activated Carbon/ Reverse osmosis & well water	836	836	9.2	680
Colorado River Water	320	832	6.4	750
State Water Project	320	933	10.2	300

much more costly, due to increasingly stringent state regulations.

In the case of Pomona - Garden State and Simpson, a concerted effort, spearheaded by the city, successfully tackled the economic/legal/institutional problem in order to support industry and conserve water. Having acquired rights to the PWRP effluent, the city initiated a marketing program supported by local elected officials and the grant-funding of activated-carbon filters by the state and EPA for the total reuse of the PWRP effluent. Their diversified reuse program, incorporating industrial process and cooling water and landscape irrigation is a model of all the factors involved in planned water conservation working together successfully. If it is possible in Pomona, by dint of effort, it should be as possible elsewhere.

ACKNOWLEDGEMENT

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THE RELATION OF PROCESS WATER QUALITY AND ITS REUSE POTENTIAL IN UNBLEACHED KRAFT PAPER AND BOARD MILLS

J.E. McCourt, P.E.
Senior Project Engineer
SCS Engineers
Bellevue, Washington 98005

Reid A. Miner, P.E.
Regional Manager
NCASI
Western Michigan University
Kalamazoo, Michigan 49008

INTRODUCTION

The pulp and paper industry has long recognized the potential benefits associated with water reuse. A review of literature dating back as far as 1935 reveals a strategy that continues to be employed; namely, the implementation of loss control programs to minimize production costs and provide cost effective environmental protection (1-9). Circumstances have, of course, changed since 1935. More restrictive environmental protection objectives as well as escalating raw material and energy costs have provided increased impetus for water reuse and load control.

One aspect of water reuse which has been the focus of much interest throughout the years is paper or board machine white water reuse. White water reuse practices have now evolved to the point where additional recycle activities often requrie close scrutiny to determine whether the recycled water will perform the required function and to define the impact of the practice on the water system and machine operation as a whole. Recognizing these information needs, the NCASI has, over the past several years, conducted an ongoing investigative effort with the following objectives:

> To define the present state of water reuse practiced in mill operations.
>
> To define the factors which have prevented or retarded further process water reuse.
>
> To determine the water quality required at various water use points in mill operations.
>
> To determine the water quality available at various source points in mill systems.
>
> To develop and maintain a data repository of process water quality characteristics and, based on experience, the suitability for reuse of the process waters at various points in the process.

The results of NCASI studies of reuse practices in recycled board mills, non-integrated fine paper mills, and non-integrated tissue and toweling mills are reported upon in NCASI Stream Improvement Technical Bulletins Nos. 282, 287, and 289, respectively (10-12). This report summarizes the results of the extension of these studies to unbleached kraft mills. The complete study is contained in NCASI Stream Improvement Technical Bulletin No. 339 (13).

To pursue the objectives of this study it was first necessary to (a) identify a number of mills with low to moderate fresh water use, (b) document the origin and quality of waters being used throughout the machine systems, and (c) document both the successful and unsuccessful water reuse practices undertaken at these mills. The mills' water reuse experiences were solicited in the course of discussions with mill personnel and recorded in questionnaire format.

Mill visits usually spanned several days during which two or more sets of samples were collected. Attempts were made to avoid sampling during upset conditions. The sampling locations varied at each mill depending upon the reuse strategies employed. Analyses performed are listed in Tables 1 and 2. The sampling and information gathering activities were undertaken at 14 unbleached kraft mills. Samples were collected from a total of 18 paper machine systems.

GENERAL WATER REQUIREMENTS, FUNCTIONS, AND QUALITY CONSTRAINTS

There are a variety of points around an unbleached kraft paper or board machine where water is required. These water use points and the approximate water requirements are listed in Table 3. In assessing strategies for water reuse it is necessary to examine the water requirements at individual water use points and judge the suitability of substituting reused water for fresh water. In making these judgments one must examine the functions of the water as well as the water quality constraints imposed by these functions and by general operational considerations.

General Constraints

There are several constraints that apply to all machine system inputs, regardless of function. First of all, the materials of construction in the machine system must be adequate to avoid excessive corrosion. Second, in almost all circumstances, enhanced solids deposition or slime formation is to be avoided. Such deposits can contribute to pitting corrosion and create plugging or product quality problems when they break loose. In addition, conditions which result in excessive foaming in machine water systems are to be avoided. Unfortunately, the physical, chemical, and biological processes which control corrosion, deposition, slime growth, and foaming are not well defined. Some of the water quality parameters which are normally assessed to reveal corrosion, scaling, slime growth, or foaming potential in machine water systems are included in Table 1.

Dilution Water

Stock Dilution. The dilution of high density brown stock to headbox consistency requires large amounts of water. In the range of high density consistencies of from 10 to 15 percent solids and headbox consistencies of from 0.5 to 1.0 percent solids, diluiton requirements of approximately 22000 to 46000 gal/ton of paper (90 to 193 m^3/metric ton) are indicated. However, the virtually universal practice of recirculating much of this water within a headbox loop suggests that it is more appropriate to consider only those dilution requirements which under normal circumstances could conceivably be satisfied with fresh water. This reduces the dilution requirements to those needed to dilute from high density consistency to a machine stock consistency of

TABLE 1. TESTS SELECTED TO CHARACTERIZE REUSED WATER QUALITY

Test	Reason for Inclusion
Total solids	Solids buildup
Total volatile solids	Organic solids buildup
Total fixed solids	Inorganic solids buildup
Suspended solids	Fiber solids buildup
Dissolved solids	Dissolved solids buildup
Dissolved solids volatile	Dissolved organic solids buildup
Dissolved solids fixed	Dissolved inorganic solids buildup, inorganic mass balance
Mesh test	Sieve particle analysis, shower plugging
Calcium	Cation balance, sizing, scale, retention
Sodium	Cation balance, dissolved solids, soda loss
Aluminum	Cation balance, retention, sizing
Chloride	Anion balance, corrosion
Sulfate	Anion balance, scale, corrosion
Total hardness	Calcium solids, carryover from pulp mill, sizing, scale, retention
Calcium hardness	Calcium solids carryover from pulp mill, sizing, scale, retention
Alkalinity	Acid buffering, carbonate levels, corrosion, chemical usage
Acidity	Base buffering capacity, corrosion
pH	Ionic equilibrium, corrosion
Conductivity	Dissolved solids, corrosion
Temperature	Thermal buildups
Linear polarization corrosion rate measurements	Uniform corrosion rate
Color	Color

TABLE 2. SCHEDULE OF WATER QUALITY ANALYSES

Block of Tests Run at the Mill

- [a]Alkalinity
- [a]Acidity
- [a]pH
- [a]Temperature
- [b]Mesh test
- [b]Corrosiveness
- [c]Calcium
- [c]Aluminum
- [c]Sodium

Block of Tests Run at Regional Center Laboratory

- [a]All solids analyses
- [a]Chloride
- [a]Sulfate
- [a]Total hardness
- [a]Color

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[a] Basic block of tests run on all sampling locations.

[b] Test run on selected sampling sites around the machine.

[c] Test only run where equipment for analysis was available.

TABLE 3· POTENTIAL SOURCE WATER USE DEMANDS AROUND THE PAPER MILL AREA[a]

Dilution Water Use	
(Excludes headbok loop recirculation from 3% machine stock to 0.5% headbox stock to 3% wire solids)	
Stock dilution (12% off the washer or decker or high density storage to 3% machine stock	6000 gpt
Excess dilution water from high density storage stock (12% solids to the paper web entering the dryer at 38% solids)	1370 gpt
Cleaner dilution	290-320 gpt
Pulper makedown (92% solids to 3% solids) Potentially intermittent use	7740 gpt
Showering Water Use	
Miscellaneous paper machine showers 1. Wire knockoff 2. Wire cleaning 3. Wire return roll } Estimated at >60% of flow 4. Headbox showers 5. Breast roll 6. Trim knockoff and cleaning 7. Internal & external couch roll showers 8. Internal press roll showers 9. Felt lub 10. Deckles and trim squirt	3200-3560 gpt
Press felt washing	2140-2370 gpt
Grooved roll shower	290-320 gpt
Sealing Water Use	
Gland seal water	860-950 gpt
Vacuum pump seal	1300-1440 gpt
Cooling Water Use	
Cooling water 1. Heat exchangers 2. Sweat dryer system 3. Mechanical cooling units 4. Air compressors 5. Hydraulic system 6. Brake drums 7. Miscellaneous equipment	3400-3780 gpt
Miscellaneous Uses	
Equipment clean-up, etc.	1070-1190 gpt

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[a] Some figures estimated from literature citation(4)
gpt = gallons/short ton

approximately 3 percent fiber. This represents a water requirement of approximately 5600 to 6400 gal/ton (23.3 to 26.7 m^3/metric ton).

Other Dilution Uses. The other significant uses of water for dilution are (a) pulper makedown, (b) elutriation on cleaners and screen rejects and (c) chemical solution make-up. The water quality characteristics of importance to the first two of these uses are included in Table 1. The water quality requirements for chemical solution make-up are very dependent upon the characteristics of specific chemicals.

Showering Waters

There are a multitude of showers and shower types on a paper or board machine; the quality of the water that can be used in any of them is related to the quantity of suspended solids contained in the water and the size distribution of those solids. The primary problem caused by these solids is shower nozzle plugging. In addition, there are several showering applications where the solids can have a detrimental effect on the process itself. Perhaps the best examples of this are felt lubrication and cleaning showers, where the potential for felt plugging must be considered.

Sealing Water

The most significant use of sealing water is associated with water ring vacuum pumps. The function of this water is to provide vacuum for water removal from the sheet and felts. Because the attainable air flow is related to the vapor pressure of the liquid used for sealing, temperature is an important water quality parameter in this application (14). In addition, concerns related to pump corrosion and abrasion dictate that the list of water quality parameters of concern be expanded to include many of those in Table 1.

Seal water is also required at pump glands but in much smaller quantities than are associated with water ring vacuum pumps. In the case of gland water, a relatively small amount is used to seal, cool, and lubricate pump packings.

Heating and Cooling Water

The quality constraints upon heating or cooling water vary depending upon the application. However, as a generalization, the quality requirements for such waters will be high due to the potential for fouling or corrosion of heat exchange surfaces, or plugging of flow channels. In instances where heating or cooling is accomplished by direct contact, water quality requirements will not only be constrained by the technique used to generate the water being used for heating or cooling but also by the intended function of the resultant mixture.

Miscellaneous Water Uses

The primary miscellaneous use of water in the paper or board machine area is for cleanup hoses.

OBSERVED WATER REUSE PRACTICES AND MACHINE SYSTEM WATER QUALTIIES

General Reuse Practices

In conceptual terms, the water reuse practices documented in this study can be described in one of three ways. These practices involve either

(a) direct white water recylcing, (b) blending, or (c) partitioning. These water reuse strategies can be further described as follows:

> Process Water Recycling: The practice of looping process water within the pulping and papermaking systems with limited continuous fresh water contact (e.g. reuse of flatbox seal pit water for stock dilution uses).
>
> Process Water Blending: The practice of looping blended process and fresh waters to various use points (e.g. the blending of vacuum pump discharge, excess filtered white water and fresh water for reuse on vacuum pump seals and paper machine showers).
>
> Process or Cooling Water Partitioning: The practice of separating limited contact process or cooling waters for recirculation or introduction into the mill fresh water supply. (e.g. recirculation loop around vacuum pump seal water system or discharge of vacuum pump seal water or cooling water to the mill fresh water supply).

These reuse patterns are often combined with the application of technologies requiring less water (e.g. low volume high pressure showers) to develop individual mill strategies for reducing effluent volumes. No single preferred strategy emerged from this study. Rather, a variety of unique combinations of these approaches were applied as best suited the needs and capabilities of individual mills. Table 4 contains a summary of the reuse practices observed at the mills in this study. What follows is a more detailed analysis of these reuse practices as well as the significance of the water qualities associated with these practices.

The Significance of Pulp Washing Practices

Because dissolved solids in machine water systems can affect production in a variety of ways, it is important to identify the source(s) of those dissolved solids. There can be no question that these materials are either carried in from the pulp mill or are added at the paper machine. However, papermill additive requirements are in many instances related to the amount of carryover from the pulp mill. Pulp mill carryforward therefore has a twofold effect upon machine system dissolved solids concentrations.

The average quality of the water carried with the pulp (squeezings) into the machine systems studied is described in Table 5. Although this data will be discussed in greater detail later, it is useful here to point out the great variation in squeezings quality from washer line to washer line. These differences are related to differences in (a) brownstock washing efficiencies (defined in terms of non-recovered liquor solids) and (b) the quality of the waters used for washing. A discussion of the factors which contribute to good pulp washing efficiency is beyond the scope of this report but, it is important to recognize that washing efficiency greatly impacts the quality of the water in the paper machine system.

Because final washer shower water quality also contributes to carryforward, it is useful to examine the types of water being used for this purpose. Generally, unbleached kraft mills use either fresh water, excess white water, or evaporator condensates for final pulp washing.

Table 4. Water Reuse Practices for the Mills Visited

Mill	Total Mill Discharge To/From Treatment (gpt)[a]	Paper Mill Discharge (gpt)[a]	Dilution Water Reuse Practices	Showering Water Reuse	Sealing Water Reuse	Heating/ Cooling	Misc.
Mill A-Linerboard							
Visit 1	4300-4320	860-1065	Filtered white water and decker filtrate used on most dilution uses outside of the headbox loop with mill supply make-up	Mill supply, a blend of 60% excess white water and 40% fresh water used on most showers during the first mill visit. On the 2nd visit more fresh water was used in operations.	Mill Supply	Mill Supply	Mill Supply
Visit 2	6130-7110	1330-1740					
Mill B-Linerboard	13000-13240	-	Cloudy white water chest used on many dilution uses outside of the headbox loop	Disc saveall clear leg water use only on saveall shower	Disc saveall Clear leg used on vacuum pumps	-	-
Mill C-Linerboard	9070-10180	-	Paper mill white water, and couch pit water, main source of dilution water use outside of headbox loop		-	-	-
Mill D-Linerboard	7040-6820	-	Couch pit water and flatbox seal pit water reused in dilution uses outside headbox loop	Mill supply was a blend of various waters vacuum pump seal discharge, fresh water and recirculated cooling water	Mill Supply Reused	Mill Supply Reused	Mill Supply Reused
Mill E-Linerboard	10380-11470	5570-4390	Wire pit overflow to white-water chest and white water storage waters reused on various dilution uses outside of headbox loop		-	-	-
Mill F-Linerboard No. 1 and No. 2 Paper Machines	10300-11110	-	Filtered white water reused on most dilution uses outside headbox loop		-	-	-

No. 1 paper machine (single headbox) is a separate white water system from No. 2 paper machine; however, both machines have similar white water reuse flow configurations.

[a] Gallons per short ton figure based on mill flow measurements and production data.

Table 4. Water Reuse Practices for the Mills Visited (continued)

Mill	Total Mill Discharge To/From Treatment (gpt)[a]	Paper Mill Discharge (gpt)[a]	Dilution Water Reuse Practices	Showering Water Reuse	Sealing Water Reuse	Heating/ Cooling	Misc.
Mill G - Linerboard							
Visit 1	7290-10130	3150-3540	Flatbox seal pit and filtered white water used on most dilution uses outside the headbox loop and excess filtered white water used on last washer	Filtered white water polished with in line strainers for reuse on many wire shower sections	-	-	-
Visit 2	9100-10980	2150-3700					
Mill H - Linerboard							
No. 1 Paper Machine	8160	3890-4510	Wire pit overflow or rich white water use on most dilution water use outside headbox loop with some white water reused on the top liner washer showers	Filtered water was flotation and fine screen treated white water reused on many wire and press section showers	Filtered white water reused on Flo-Vac system	-	-
No. 2 Paper Machine	7250-8160	3770-3930	Wire pit overflow or rich white water and filtered white water use on most dilution water uses outside of the headbox loop and some rich white water used on top liner washer	Filtered white water reused on many wire showers and press roll showers	-	-	-
Mill I - Linerboard	~10000	-	Wire pit overflows, rich white water and filtered white water use on most dilution uses outside of headbox loop	Polished white water (filtered white water passed through an in-line strainer)reused on wire return roll and wire knockoff showers. Press shower on a recirculation loop	Cooling tower re-circulation system shared by corrugated & linerboard machines with fresh water blow down	-	-

[a] gallons per short ton figure based in mill flow measurements and production data

Table 4. Water Reuse Practices for the Mills Visited (continued)

Mill	Total Mill Discharge To/From Treatment[a] (gpt)	Paper Mill Discharge[a] (gpt)	Dilution Water Reuse Practices	Showering Water Reuse	Sealing Water Reuse	Heating/ Cooling	Misc.
Mill J - Linerboard	9200-10050	-	Wire pit overflow-white water chest water and cloudy chest water reused on most dilution water uses outside of headbox loop		-	-	-
Mill K - Linerboard	9070	~4690	White water chest water reused on most dilution water uses outside of the headbox loop	Filtered white water used on most wire section showers	Flo-Vac on filtered white water, fresh water system blowdown to mill supply with collection and cooling tower due to high chloride content in fresh water		
Mill L - Linerboard	6980-8900	-	White water chest water reused on most dilution uses outside of the headbox loop	Filtered white water used on wire knockoff showers. Other wire showers had been using filtered white water; however, poor saveall performance prevented reuse on these other showers	-	-	-
Mill M - Bag No. 2 Paper Machine	7860-8900	7060-7400	Central white water storage water use on most dilution water uses outside of the headbox loop	Filtered white water passed through in-line strainers reused on breast roll, wire knockoff and wire return roll showers	-	-	-

[a] gallons per short ton figure based on mill flow measurements and production data

Table 4. Water Reuse Practices for the Mills Visited (continued)

Mill	Total Mill Discharge To/From Treatment (gpt)[a]	Paper Mill Discharge (gpt)[a]	Dilution Water Reuse Practices	Showering Water Reuse	Sealing Water Reuse	Heating/ Cooling	Misc.
Mill M-Bag No. 5 Paper Machine			Central white water storage water use on most dilution water uses outside of the headbox loop		Vacuum pump seal water recirculated with a fresh water blow-down	-	-
Mill W - No. 1 Paper Machine (Single Headbox) Bag	15080-15260	-	Filtered white water use of most dilution uses outside of the headbox loop and on top liner washer showers	In-line strainer polished filtered white water reused on wire knockoff showers	In-line strainer polished filtered white water use on vacuum pump seals	-	-
No. 2 Paper Machine (Twin Headbox) Linerboard			Filtered white water use on most dilution uses outside of the headbox loop	In-line strainer polished filtered white water reuse on wire knockoff showers	-	-	-

[a] gallons per short ton figure based on mill flow measurements and production data

TABLE 5. SUMMARY OF BROWNSTOCK WASHER AND DECKER STOCK SQUEEZINGS WATER QUALITY

Variable Description	Sample Size	Mean	Standard Deviation
Temperature (°C)	15	61	10.5
pH	27	10.5	0.7
Dissolved Solids (ppm)	27	4035	2951
Dissolved Solids-Ash (ppm)	26	2371	1849
Dissolved Solids - Volatile (ppm)	26	1711	1246
Conductivity at 25°C (μmhos/cm)	27	3095	2137
Color (pcu or ppm)	27	2895	2571
Total Hardness (ppm $CaCO_3$ equivalent)	27	24	20
Alkalinity (ppm $CaCO_3$ equivalent)[a]	27	1216	936
Acidity (ppm $CaCO_3$ equivalent)[b]	27	0	0
Sulfate (ppm)	27	291	292
Chloride (ppm)	26	38	27

[a] Titrated to pH 3.7

[b] Titrated to pH 8.3

Although the use of condensates was not addressed in this study, it should be pointed out that concerns relative to the effect of condensate use upon product odor persist in mills making food grade board and kraft paper. The nature and extent of this problem have not been quantified but efforts to do so are warranted.

The use of white water for pulp washing can have a two-fold significance. First in those cases where clean shower water has been displaced, the practice contributes to increased solids concentrations in the machine water system. The effects of such carryforward upon headbox water quality were especially evident during the sampling program at mill G. The second sampling run was conducted under conditions of high pulp mill carryforward. This situation subsequently required the substitution of fresh water for white water on the final pulp washer. An abbreviated sampling program was conducted the following day to examine the impact of this change. Over this period the headbox dissolved solids concentration, declined from 6200 ppm to 4750 ppm. A review of the machine operation over this period suggested that this improvement was attributable to the use of fresh water for final pulp washing.

In addition to the increased carryforward effect, the use of white water for brownstock washing can, under certain circumstances, introduce papermaking chemicals into the recovery system. Aluminum, calcium, and silica compounds are usually the materials of greatest concern due to their scale formation tendencies. The extent of countercurrent filtrate usage was not established in these mill visits. However, a mill not sampled in this study has reported to the authors that the use of even limited amounts of machine white water for pulp washing has contributed significantly to their evaporator scaling problems. Contradictory reports from other mills suggest that this practice warrants additional study.

Overall then, the impact of pulp mill carryforward upon white water quality and machine water reuse operations can hardly be overemphasized.

Stock Dilution and Headbox Water Quality

One of the major areas of water reuse is in dilution. The pulp stock is diluted from 15% solids at the pulp washers to 0.5% solids in the paper machine headbox. This water is recaptured for dilution by the papermaking process when the pulp is dewatered by gravity and vacuum through the paper machine wire section. This water flows into the wire pit and flat box seal pit beneath the paper machine. From these white water storage facilities, this water is recirculated by the fan pump and auxillary pumps to dilute the pump to headbox consistency.

At all of the mills included in this study, primary headbox loop waters were drawn directly from the wire pit. Secondary headbox loop waters were supplied from the flatbox seal pits of eight machines and the wirepits of the remaining five machines. On these latter five machines wirepit water quality was impacted to a degree by flatbox seal pit overflow.

The quality of the water in the headbox loop is of great significance to water reuse practices in two respects. First, this loop must provide a suitable environment for preparing the fibers for the machine. Second, the quality of the water in this loop can directly affect the potential for reuse of white water elsewhere on the machine, especially in those applications sensitive to dissolved solids. The quality of the water in the headbox loop is determined by the quantities and qualities of (a) pulpmill carryforward, (b) paper machine additives, and (c) dilution water. The first two of these items have already been addressed. However, the sources and qualities of dilution water documented in this study remain to be discussed.

The normal practice of recycling white water for stock dilution assures that dilution water qualities and headbox water qualities will be closely related. Therefore, to observe the effects of dilution water quality, it is appropriate to examine the headbox water qualities which were documented in this study and examine the factors of importance in operating at these headbox conditions. Tables 6 and 7 provide the average headbox conditions identified. In addition to identifying the range of headbox water qualities existing in this segment of the industry, the sampling program revealed a variety of mill problems related to headbox water quality.

The relationships between pulp mill carryforward, headbox water quality and water system operational problems were often cited by the mills in this study. This effect was especially evident during the sampling at Mill G. An increase in headbox dissolved solids concentration of from 3300 to 6000 ppm was directly attributable to an increase in washed pulp squeezings (liquid) dissolved solids of from 2800 to 8100 ppm. Excessive foam generation, increased scale or slime formation, increased acid and alum usage, and accelerated corrosion were the concerns most frequently attributed to pulp mill losses by the mill personnel surveyed in this study.

Headbox total dissolved solids concentrations (TDS) are also related to the amount of fresh water used. The data from mill A demonstrates this relationship. The machine fresh water usage increased from approximately 1700 gal/ton to 2300 gal/ton during a period between two sampling visits. This increase corresponded to a decrease in headbox TDS concentrations of from 3000 to 3800 ppm during the initial visit, down to 2200 to 2400 ppm TDS under less tightly closed conditions. Figure 1 demonstrates this general trend as illustrated by the data collected at all of the mills visited.

Based upon the data generated in this study, there appears to be a lower limit of approximately 1000 mg TDS/L in headbox waters, presumably related to baseline chemical requirements at the machine. On the other hand, the experiences of mills A and G may provide insight into the maximum workable levels of headbox TDS. Although a period of high pulp mill carryforward at mill G resulted in headbox TDS concentrations of 6000 to 7000 mg/L, observations by mill personnel and corrosion rate measurements (to be discussed later) suggested that continued operation under these conditions would have been difficult and costly. The remaining experience at mills G and A identifies 3500 to 4000 mg/L as the highest headbox TDS concentrations documented in this study at acceptable operating conditions. The sampling program at Mill F, however, demonstrated the potential for misinterpretation of headbox water quality data based only upon total dissolved solids (TDS) concentrations. At mill F, white liquor clarification problems increased headbox dissolved solids levels from 1580 to 3050 ppm. Even at this increased level, the headbox TDS concentration was well within the range observed at other mills. However, these solids created the highest headbox hardness levels observed in the study (1200 mg $CaCO_3$/L or approxiamtely five times the average headbox value). The resulting operational problems included the generation of a thick, stable wet end foam which necessitated increased discharges of white water to the

TABLE 6. AVERAGE PRIMARY HEADBOX WATER QUALITY AMONG THE MILLS VISITED

Variable Description	Number of Samples	Mean	Standard Deviation
Temperature (^{o}C)	48	53.5	5.3
pH	49	5.6	0.7
Total Solids (ppm)	48	7064	2292
Total Solids-Ash (ppm)	48	2081	1192
Total Solids-Volatile (ppm)	48	4983	1456
Dissolved Solids (ppm)	49	2409	1296
Dissolved Solids-Ash (ppm)	47	1949	1178
Dissolved Solids-Volatile (ppm)	47	423	196
Suspended Solids (ppm)	49	4548	1505
Conductivity at 25^{o}C (μmhos/cm)	49	2436	1287
Color (pcu or ppm)	48	292	313
Total Hardness (ppm $CaCO_3$ equivalent)	49	249	199
Alkalinity (ppm $CaCO_3$ equivalent)[a]	48	130	85
Acidity (ppm $CaCO_3$ equivalent)[b]	48	66	36
Sulfate (ppm)	49	1194	770
Chloride (ppm)	49	24	15
Fresh Water used in Paper Mill (gpt)	34	4205	1737
Water Discharge Paper Mill (gpt)	30	4595	2222
Total Effluent Pulp/Paper Mill (gpt)	47	9450	2563

[a] Titrated to pH 3.7

[b] Titrated to pH 8.3

TABLE 7. AVERAGE SECONDARY HEADBOX WATER QUALITY AMONG THE MILLS VISITED

Variable Description	Number of Samples	Mean	Standard Deviation
Temperature (°C)	35	53.6	6.1
pH	34	5.4	0.6
Total Solids (ppm)	35	8014	2135
Total Solids-Ash (ppm)	35	2123	1249
Total Solids-Volatile (ppm)	35	5891	1660
Dissolved Solids (ppm)	35	2423	1371
Dissolved Solids-Ash (ppm)	33	1945	1219
Dissolved Solids-Volatile (ppm)	33	424	236
Suspended Solids (ppm)	35	5507	1495
Conductivity at 25°C (µmhos/cm)	35	2507	1337
Color (pcu or ppm)	35	176	155
Total Hardness (ppm $CaCO_3$ equivalent)	35	258	204
Alkalinity (ppm $CaCO_3$ equivalent)[a]	33	119	74
Acidity (ppm $CaCO_3$ equivalent)[b]	34	76	39
Sulfate (ppm)	35	1244	777
Chloride (ppm)	35	27	17
Fresh Water used in Paper Mill (gpt)	21	3386	1587
Water Discharge Paper Mill (gpt)	19	3468	1639
Total Effluent Pulp/Paper Mill (gpt)	34	9254	2570

[a] Titrated to pH 3.7

[b] Titrated to pH 8.3

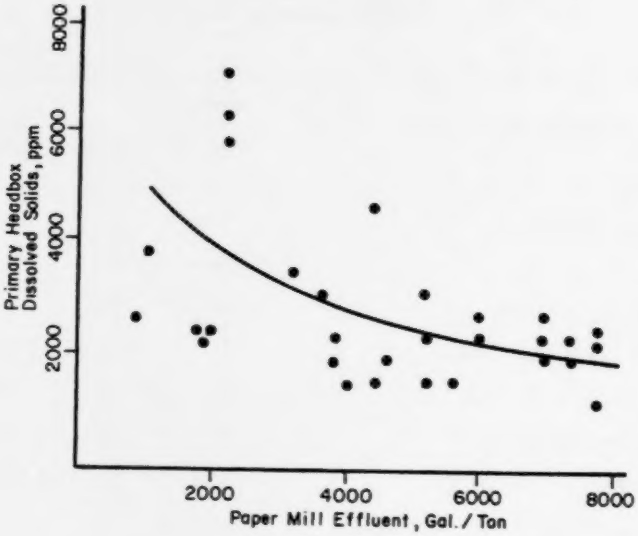

Figure 1 The Impact of Water Use on Headbox Dissolved Solids Concentrations

sewer. Therefore, it must be observed that headbox TDS concentrations of less than 3500 ppm can result in unacceptable machine operation depending upon the nature of the solids.

Corrosion. One of the most important issues related in part to dissolved solids concentrations in the paper machine water systems is corrosion. This issue was addressed in three ways. First, information related to materials of construction and corrosion experience was solicited during the mill sampling program. Second, in situ uniform corrosion data was collected on site using linear polarization equipment. Third, headbox water samples from twelve machines were submitted to laboratory potentiodynamic pitting and crevice corrosion studies on 304 and 316 L stainless steels. These laboratory studies were conducted at the Institute of Paper Chemistry under the direction of Dr. David Bowers as part of the Institute's general funded research program on corrosion in paper machine systems.

Thirteen of the 18 paper machines sampled in this study had headboxes constructed of 316 stainless steel, while the remaining five had headboxes constructed of 304 stainless steel. The fourdrinier rails, saveall pans or trays, and piping were constructed of 316 stainless steel on half of the machines studied. Seven other machines were fitted with 304 stainless steel at these points while the remaining two machines contained other materials such as mild steel or fiberglass.

The corrosion data generated in this study is shown in Table 8. The average of the uniform corrosion rates on 1020 mild steel, measured at the locations in Table 8, was approximately 36 milliinches per year. Attempts to correlate uniform corrosion rates with a variety of water quality and reuse parameters yielded the results in Table 9. It is not

Table 8. Corrosion Measurements in White Water

MILL	MACHINE	RUN	1020 MILD STEEL UNIFORM CORROSION RATE;MILLIINCHES PER YR.	SAMPLE LOCATION	ACTIVATION POTENTIAL MARGIN OF SAFETY			
					Pitting		Deposit	
					304SS SCE MV	316LSS SCE MV	304SS SCE MV	316LSS SCE MV
A	1	5	45-55	Primary Headbox	1100	1140	300	800
C	1	1,2	60-65	Wire Pit	-	-	-	-
E	1	2	22	Wire Pit	957	822	980	580
F	1	1	12	Primary Headbox	-	-	-	-
F	2	2	37	Primary Headbox	1310	1283	565	535
G	1	2	90	Screen Reject Tank	1466	1402	660	805
G	1	5	-	Screen Reject Tank	577	707	20	300
H	1	2	40	Riffler	-	-	-	-
H	2	2	10-20	Wire Pit	-	-	-	-
I	1	1	12-20	Screen Rejects Water	-	-	-	-
J	1	3	22	Wire Pit	-	-	-	-
K	1	2	-	Primary Headbox	1190	1414	580	600
L	1	2,3	35-45	Flatbox Seal Pit	-	-	-	-
M	1	2	8	Headbox	-	-	-	-
M	1	5	-	Headbox	1400	1420	800	800
N	2	2	34	Primary Headbox	-	-	-	-

TABLE 9. CORRELATIONS OF IN SITU UNIFORM CORROSION RATES ON 1020 MILD STEEL PROBES WITH WATER REUSE PARAMETERS

Uniform Corrosion Rate Correlated with the Following Variables	Sample Size	Coefficient of Correlation
Temperature (^oC)	12	0.30
pH	12	-0.27
Total Solids (ppm)	12	0.51
Total Solids-Ash (ppm)	12	0.59
Total Solids-Volatile (ppm)	12	0.44
Dissolved Solids (ppm)	12	0.44
Dissolved Solids-Ash (ppm)	12	0.14
Dissolved Solids-Volatile (ppm)	12	0.19
Suspended Solids (ppm)	12	0.54
Conductivity at 25^oC (μmhos/cm)	12	0.69
Color (pcu or ppm)	12	-0.13
Total Hardness (ppm $CaCO_3$ equivalent)	12	0.07
Alkalinity (ppm $CaCO_3$ equivalent)[a]	12	-0.25
Acidity (ppm $CaCO_3$ equivalent)[b]	12	0.16
Sulfate (ppm)	12	0.59
Chloride (ppm)	12	0.13
Fresh Water used in Paper Mill (gpt)	7	-0.68
Water Discharge Paper Mill (gpt)	7	-0.60
Total Effluent Pulp/Paper Mill (gpt)	11	-0.06

[a] Titrated to pH 3.7

[b] Titrated to pH 8.3

surprising that no single parameter adequately defined uniform corrosion rate. Among the strongest correlations were: (a) decreased uniform corrosion with increased fresh water usage, and (b) increased uniform corrosion with increased conductivity. Perhaps the greatest surprise in Table 9 is the lack of correlation between decreased pH and increased uniform corrosion rate. In the pH range of 6 to 13 Bowers has determined that conductivity and pH both strongly impact mild steel uniform corrosion rates in white water (15). It is possible that the effect of pH was less evident in this study due to (a) the comparatively narrow pH range examined (4.0 to 7.3), (b) the lack of extensive data from individual systems, and (c) the major effect of general water chemistry upon mild steel corrosion in this pH range.

The pitting and crevice corrosion analyses conducted on 304 and 316 L stainless steels provided the basis for several observations. First, the pitting analyses suggested similar potential margins of safety for the various waters tested. The magnitude of these margins are an indication that pitting corrosion may pose only limited problems in white water recycle systems. On the other hand, the potential margins of safety for deposit or crevice corrosion proved to be more varied from mill to mill. In particular, the low margin of safety measured on a sample collected at mill G during a run in which headbox TDS concentrations exceeded 6000 ppm, suggests that 304 stainless steel may be inadequate under such conditions. The deposit or crevice corrosion data on 316L stainless steel suggested that this material would probably not incur severe deposit or crevice corrosion in the white waters studied herein. However, it is noteworthy that mills H and I cited crevice corrosion problems under barium sulfate deposits in 316L stainless steel headboxes.

Headbox Temperature. One important aspect of machine closure is the effect upon headbox temperatures. The temperatures documented in this study ranged from 104 to 144°F (40 to 62°C). The significance of this thermal buildup, as revealed by mill experience, is discussed later.

Headbox Loop Stability. One aspect of this study was the determination of the degree of stability in machine white water systems. Because very little continuous data was generated, it was necessary to make this determination by analyzing the amount of change which occurred from one sample run to another on a given machine. A summary of these analyses performed on headbox waters is shown in Table 10. It is possible to examine the information in this table in terms of four different parameter types; namely, (a) those which are uncontrolled, but to a large extent independent of normal process variations, (b) parameters which are tightly controlled during normal machine operation, (c) parameters whose normal variabilities at a given mill are solely relatable to pulp mill carryforward, and (d) parameters whose variabilities are affected by both pulp mill carryfoward and machine operation. Table 10 demonstrates relatively little variability in machine control variables, especially pH and temperature. The relatively small variability in chloride concentrations may be explained by assuming that the major chloride inputs are contained in fresh water of fairly consistent quality. It is interesting to note that the parameters most likely to vary substantially are those closely relatable to pulp mill carryforward, for instance color and to a lesser degree, total alkalinity. This suggests that headbox water quality variability, and subsequently much of the overall white water system variability can be attributed, either directly or indirectly to pulp

TABLE 10. STABILITY OF PRIMARY HEADBOX WATER QUALITY

Parameter	Change in Water Quality From One Sampling Run to the Next- Number of Observed Changes of Specified Magnitude				
	0-10%	10-20%	20-30%	>30%	Total
Temperature	11	0	0	0	11
pH	16	1	1	0	18
Total Solids	9	5	3	0	17
Total Solids-Ash	6	5	3	3	17
Total Solids-Volatile	6	7	4	0	17
Dissolved Solids	7	5	3	3	18
Dissolved Solids-Ash	7	5	3	2	17
Dissolved Solids-Volatile	6	2	3	5	16
Suspended Solids	8	6	2	2	18
Conductivity	5	6	6	1	18
Color	1	4	0	12	17
Total Hardness	7	6	1	4	18
Total Alkalinity[a]	5	1	1	10	17
Total Acidity[b]	8	3	1	5	17
Sulfate	9	4	2	3	18
Chloride	11	2	2	3	18
Dissolved Oxygen	1	0	0	0	1
Sodium	1	1	0	0	2

[a] Titrated to pH 3.7

[b] Titrated to pH 8.3

mill carryforward.

Another aspect of headbox loop stability is related to the ability to consistently provide adequate quantities of white water for stock dilution, especially during upsets and startups. In higher water use machine systems, intermittent requirements for increased quantities of water can be satisfied to a large extent with fresh water. However, mills that are closing up their water systems have often preferred to satisfy these requirements with white water to keep the water system in balance and minimize sewer losses. Accordingly, 87 percent of the mill personnel surveyed in this study identified white water storage capacity as an important factor in low water use systems. All of the machines included in this study had unclarified white water storage capacity of less than 750 gal/ton. In addition, with one exception, these systems contained less than 350 gal/ton of clarified white water storage capacity. Mill A, which recirculated clarified white water to the fresh water treatment system, indicated a storage capacity of greater than 750 gal/ton for this water.

Water Reuse on Showers

Shower water requirements total approximately 6500 gal/ton of production, so the use of recycled water on selected showers is an essential component of any program to reduce machine room losses. Eleven of the 18 mills in this study were using recycled water in at least one shower application. With the exception of suspended solids concentrations the average quality of white water used on showers was similar to dilution waters. However, the total suspended solids levels of shower waters averaged 128 ppm compared to an average level of 550 ppm in dilution water. This situation illustrated the more extensive use of solid-liquid separation equipment such as savealls and deckers on white water reused for showering compared to that used for dilution. Table 11 shows that wire section shower water requirements are those most commonly satisfied using recycled water while felt showers are among those least often engaged in this practice. The water quality data in Table 11, also suggests that quality requirements are least restrictive on wire section showers and most restrictive on felt showers. The ranking shown in the table should not be applied too rigorously, however, since shower nozzle types and sizes were variable from mill to mill. Three mills indicated that they had discontinued using white water on showers. Their experiences are summarized in Table 12.

In addition to the problems associated with system closure in general, the use of reycled water on showers creates the potential for nozzle plugging problems. The measures applied by the mills in this study to alleviate nozzle plugging included the following:

(1) The selection of appropriate nozzle orifices and operating pressures or the use of self cleaning shower nozzles.

(2) The use of effective solid-liquid separation devices. Nine of the 11 machines applying white water to showers were fitted with post saveall solids separation devices such as in-line strainers, or fine screens. However, it must be noted that many mill personnel suggested the need for additional white water solids separation equipment, especially if further closure was envisioned. This need was related to the potential for hydraulic or solids overloading, maintenance problems and general upsets which would jeapordize the continuity of shower water supply.

TABLE 11. THE EXTENT OF ACCEPTABLE RECYCLED WATER USAGE ON SELECTED SHOWERS

	Number of Mills Using White Water	TSS Range	mg/L on 100 Mesh Range
Wire knockoff	11	10-410	<0.5-161
Wire return roll	9	10-225	<0.5-8.8
Trim knockoff	7	10-85	<0.5-2.7
Breast roll	6	10-100	<0.5-8.8
Headbox	6	10-60	<0.5-2.5
Press roll	5	10-60	<0.5-2.5
Couch roll	3	10-85	<0.5- ?
Felt lubrication	3	10-60	<0.5-2.5
Felt cleaning	2	10-60	<0.5- ?

TABLE 12. UNSUCCESSFUL ATTEMPTS TO USE WHITE WATER ON SELECTED SHOWERS - PRACTICES THAT HAVE BEEN DISCONTINUED

			Water Quality		
Mill	Shower	Water Source	TSS	mg/L on 100 Mesh	Reasons for Discontinued Use
C	Broke decker	Combined vacuum pump seal water and press water	30-40	1.6	Shower plugging
E	Wire	Broke decker filtrate			Shower plugging
M-Machine 2	Wire	Filtered white water-clear leg disc saveall plus Durco strainers			Occasional hydraulic overloading of the disc saveall, mechanical problems with the strainer, increased cleanup time required to handle deposits attributed to the use of recycled water on showers

(3) Blending filtered white water with fresh water.

(4) Designing piping and tankage for white water use so that solids accumulation would be minimized. Important facets of such designs were (a) flushing tees on shower headers, and (b) adequate allowances for velocity changes in shower headers and general piping and tankage.

(5) Maintenance programs to keep white water system components in good operating condition.

In spite of the measures employed to minimize shower plugging, intermittent problems are inevitable. For this reason, the continued use of white water on showers is certainly enhanced by (a) shower water systems designed to allow flexible responses to water reuse problems and (b) the continuing commitment of mill personnel.

Water Reuse in Sealing Applications

A summary of sealing water quality parameters measured on eight machines is shown in Table 13. The average values for these eight machines are contained in Table 14. The fact that sealing waters were generally cleaner than dilution or shower waters reflects a separation of process white waters and sealing waters. Sealing water quality was variable, depending on the sealing use (vacuum pumps, gland or Flo-Vac sealing), the source of the sealing water and the degree of contamination with process waters. Sealing water reuse practices on the eight paper machines sampled were as follows:

> Two machines used filtered white water on Flo-Vac applications (Mills H and K);
>
> Two machines supplied vacuum pump and gland sealing requirements with a blend of treated white water and fresh water (Mills A and D);
>
> Two machines supplied vacuum pump seals with filtered or polished white water (Mills B and N);
>
> One machine used a vacuum pump seal water recirculation system with a cooling tower (Mill I);
>
> One machine used a vacuum pump seal water recirculation system with fresh water blow down (Mill M).

The problems associated with the use of reused water for sealing included elevated operating temperatures, scaling on Flo-Vac belts, plugging of seal water lines, corrosion of mild steel parts, and slime accumulation in the vacuum pump seal water and the paper machine white water. On the average, sealing waters picked up approximately 140 mg total dissolved solids and 30 mg total suspended solids per liter of water used on the seals. The average temperature rise across the vacuum pumps was 18°C. The data in Table 14 identifies an average sealing water temperature of 98°F (36.5°C) for the machines in this study. Mill B was using the hottest seal water documented in this study. In this case saveall clear leg water at 120°F (49°C) was being used on vacuum pump seals. Other factors contributing to successful water reuse in sealing applications included the use of special stainless steel fittings to minimize corrosion, flushing

TABLE 13. Water Reuse in Sealing Applications

	Sealing Water In					Sealing Water Out				
Mill	Temp °C	TDS mg/L	TSS mg/L	pH	Color pcu	Temp. °C	TDS mg/L	TSS mg/L	pH	Color pcu
A	26.5	1180	<50	7.1	250	38	1080	100	7.3	250
B	48-49	1270	110-600	6.1-6.5	70-120					
D	29	490	20	7.4	35	40	880	60	7.6	125
H[a]	44-54	990-2370	20-50	5.3-5.7	30-90					
I	23	250	30	6.7	190	39	420	70	7.4	340
K[a]	45	2380-2530	20	7.4-7.7	70-80					
M	42	170	40	7.5	25	57	210	60	7.3	30
N	37	590-650	30-50	7.6	50-70					

[a] Filtered White Water Used on Flo-Vac Seals Only

TABLE 14. SUMMARY OF SEALING WATER REUSE QUALITY AMONG MILLS SAMPLES

Variable Description	Sample Size	Mean	Standard Deviation
Temperature (^{o}C)	16	36.5	8.0
pH	16	7.1	0.5
Total Solids (ppm)	16	1066	740
Total Solids-Ash (ppm)	16	784	599
Total Solids-Volatile (ppm)	16	282	184
Dissolved Solids (ppm)	16	1005	714
Dissolved Solids-Ash (ppm)	16	753	599
Dissolved Solids-Volatile (ppm)	16	252	260
Suspended Solids (ppm)	16	68	145
Conductivity at 25^{o}C (μmhos/cm)	16	1115	776
Color (pcu or ppm)	16	146	107
Total Hardness (ppm $CaCO_3$ equivalent)	16	141	104
Alkalinity (ppm $CaCO_3$ equivalent)[a]	15	111	65
Acidity (ppm $CaCO_3$ equivalent)[b]	15	7	3
Sulfate (ppm)	16	437	348
Chloride (ppm)	16	26	17
Fresh Water Used in Paper Mill (gpt)	13	3094	1969
Water Discharge Paper Mill (gpt)	8	2634	2451
Total Effluent Pulp/Paper Mill (gpt)	16	8852	3689

[a] Titrated to pH 3.7

[b] Titrated to pH 8.3

valves to reduce line plugging, temperature control on the seal water, and in-line strainers or water treatment to minimize plugging from large solids.

The Use of Recycled Water for Energy Transfer

The wide assortment of energy transfer water reuse practices made it extremely difficult to characterize energy transfer water reuse quality. Mills A and D used combined fresh and white waters for energy transfer. A number of mills collected non-contact or limited process contact paper machine waters for reuse on felt showers or reintroduction into the mill fresh water supply. Other mills collected hot pulp mill waters or condenstaes for use on paper mill hoses or for use in reducing chloride levels in secondary headbox waters. Table 15 contains the average water quality parameter values for the energy transfer waters in use at the mills in this study.

The problems associated with energy transfer waters were generally associated with the quality of the fresh water supply rather than water reuse practices. These fresh water quality problems included water storage basin contamination by blowing bark or ash, high solids carryover from cold lime softening, and high chloride levels.

General Problems Associated with Water Reuse

Reduced fresh water usage on paper machines generally caused increased temperatures and increased dissolved solids and fiber fines concentrations in machine water systems. Table 16 lists the operational problems which were attributed to these increases by mill personnel interviewed for this study. It is interesting to note that other than line and nozzle plugging problems, the only operational difficulty responsible for increased fresh water usage was fiber fines buildup. The accumulation of these fines was generally controlled by (a) purging them from the system in top liner, (b) using careful refining, and/or (c) applying fine solids removal techniques. Several mills attributed steam savings to the increased temperatures. On the other hand, at several mills these elevated temperatures also caused problems with machine room air conditioning systems and water seals on vacuum pump operation.

Increases in dissolved solids concentrations caused a number of operational difficulties. Corrosion and foaming have been previously addressed. Several mills noted that cleaning and wash-up practices were especially important in systems with elevated dissolved solids concentrations. Barium and calcium deposits were identified as being of special concern.

Slimicide use generally increased with increased white water reuse. The role of increased temperature in promoting or inhibiting slime growth was not identified.

General Benefits Associated with Water Reuse

The replacement of fresh water with reused water at any point in a mill will almost always decrease effluent volumetric flow rate. There may however, also be load reductions or energy savings associated with such practices. Very few mills were able to attribute specific load reductions or energy savings to individual reuse practices. A scarcity of detailed records and the complexities introduced by a variety of

TABLE 15. SUMMARY OF HEATING AND COOLING WATER REUSE QUALITY AMONG MILLS SAMPLED

Variable Description	Sample Size	Mean	Standard Deviation
Temperature (^{o}C)	8	32.5	5.0
pH	8	7.2	0.3
Total Solids (ppm)	9	1071	677
Total Solids-Ash (ppm)	9	741	377
Total Solids-Volatile (ppm)	9	330	362
Dissolved Solids (ppm)	9	1040	621
Dissolved Solids-Ash (ppm)	9	672	388
Dissolved Solids-Volatile (ppm)	9	368	407
Suspended Solids (ppm)	9	44	86
Conductivity at 25^{o}C (μmhos/cm)	8	950	342
Color (pcu or ppm)	8	164	124
Total Hardness (ppm $CaCO_3$ equivalent)	9	114	83
Alkalinity (ppm $CaCO_3$ equivalent)[a]	8	136	56
Acidity (ppm $CaCO_3$ equivalent)[b]	8	10	1
Sulfate (ppm)	9	372	204
Chloride (ppm)	8	18	7
Fresh Water used in Paper Mill (gpt)	7	1383	358
Water Discharge Paper Mill (gpt)	9	2342	2106
Total Effluent Pulp/Paper Mill (gpt)	9	5612	1283

[a] Titrated to pH 3.7

[b] Titrated to pH 8.3

TABLE 16. PRESENTATION OF WATER REUSE PROBLEMS AND RESOLUTIONS

	Number of Observations From The Eighteen Paper Machines With Water Reuse Problems Resolutions	
Water Reuse Problems	Returned to Fresh Water	Problems Tolerable
Suspended Solids Build Up	3	11
Plugging of lines and/or nozzles	2	11
Deposits in or on Wet End Equipment	0	4
Fine Fiber Build up in Headbox Loop	1	3
Dissolved Solids Build Up	0	17
Corrosion	0	14
Foaming	0	16
Scale Formation	0	8
Slime	0	14
Odor	0	3
Temperature Build Up	0	5
Paper Machine Room Air Conditioning	0	3
Excess Heated Water	0	0
Increased Temperature in Sealing Water	0	2

process variables were responsible for this inability to establish a clear correlation. Mills A and M indicated that their close-up programs had resulted in steam savings in excess of \$.20 per ton of production (1979). As a result of an active water reuse program, mill A experienced reductions in raw waste flow, BOD and suspended solids loads of 40, 20, and 50 percent respectively. However, it must be recognized that the amount of load reduction associated with increased water reuse at a given mill will depend entirely upon the manner in which water is being reused and the specifics of the mill's production facilities. It is clear that the individual contributors to a mill's raw waste load must be scrutinized before the effects of closure can be known.

CONCLUSIONS

1. A review of the water reuse practices on 18 unbleached kraft paper and board machines at 14 separate mills discharging between 4300 and 15,250 gal/ton (18.2-63.5 m^3/ton) did not reveal a preferred reuse strategy. However, a number of these systems did have elements in common.

> In all cases, machine white water was used to supply some or all stock dilution requirements.
>
> Eleven machines had shower bars operating on filtered white water. In 9 of 11 cases, post-saveall solids removal devices were employed to produce shower water of acceptable quality.
>
> Water ring vacuum pumps were operated using reused water on eight machines. The resulting reduction in fresh water usage was variable depending upon the specifics of the reuse scheme.

2. The uniform corrosion rate on 1020 mild steel was variable from machine to machine. Corrosion rates of from 8 to 90 milliinches per year were documented. These rates were found to increase with decreased fresh water usage and increased conductivity. The potential for crevice corrosion of 304 stainless steel was documented on a white water sample containing more than 6000 ppm total dissolved solids. White waters containing less than 4500 ppm total dissovled solids did not exhibit this potential. Mill experience suggests the potential for corrosion problems under barium sulfate deposits on 316L stainless steel.

3. The highest acceptable headbox total dissolved solids concentrations measured were 3500 to 4500 ppm. However, lower concentrations have caused difficulties depending upon the nature of the dissolved materials. Headbox temperatures as high as 62 degrees centrigrade were documented.

4. Pulp mill carryforward was identified as a contributor to elevated dissolved solids concentrations in machine water systems. Headbox water quality variability was attributed in part to variable carryover quality.

5. The successful use of white water on showers has been associated with:

(a) the selection of appropriate nozzle orifices and operating pressures or the use of self cleaning showers.

(b) effective saveall and post-saveall device operation.

(c) the use of blends of fresh and white waters.

(d) flexible shower water supply systems designed for white water usage.

(e) adequate maintenance.

(f) management and operating personnel commitment.

6. Attempts to relate specific overall load reductions to paper machine fresh water use suggest that such relationships are difficult to interpret in the absence of more detailed information about pulp and paper mill operations. Individual mill experiences do, however, demonstrate generally reduced raw waste loads as fresh water use is reduced in pulp and paper mills.

7. The results of this study identify at least three aspects of water reuse which warrant more detailed examination:

The fates and impacts of materials contained in pulp mill carryforward and machine additives must be better defined;

Methods for sizing white water storage capacity and strategies for its optimum utilization need to be demonstrated; and

A need exists for a broader base of experience regarding the ability of available white water solids separation devices to consistently produce filtered waters or reusable quality.

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OPERATIONAL PROBLEMS RESULTING FROM INCREASED PAPER MILL WHITE WATER REUSE: CORROSIVITY AND FOAMING

George R. Lightsey
Associate Professor

Ginger D. Singletary
Graduate Student

William B. Hall
Professor

Harold A. Koelling

Professor

Department of Chemical Engineering
Mississippi State University
Mississippi State, MS 39762

INTRODUCTION

During the last few years there has been a great deal of effort expended developing methods to reduce water consumption in the pulp and paper industry in order to better meet waste water treatment requirements.[1,2] One successful approach, particulary with new pulp and paper mills, has been to completely close the water cycle with essentially no discharge. Rapson and Reeve have published several studies dealing with closed cycle bleached kraft mills.[3,4] Closed water systems in secondary fiber mills have been sucessfully operating for several years.[5,6]

For existing mills, optimum cost for achieving an acceptable effluent can most often be met by a combination of internal water reuse and external waste treatment.[7] An economic analysis by Hurst-Gaul showed a 3-to-1 capital cost advantage for water reuse versus effluent treatment.[8]

One of the major methods used to reduce water consumption has been reuse of water from the paper machine. The water from a paper machine, called white water, is presently only partially recycled. Most mills average 80% white water reuse within the paper machine area; nevertheless, the huge volumes of white water produced make even higher reuse rates attractive. Closing of the paper machine white water system, while desirable, can cause severe problems.[9] Surveys of pulp and paper mills in 1975 and 1976 that had begun practicing extensive water reuse showed several major problem areas.[10,11] Increased corrosivity and foaming of white water were two of the most serious and common problems reported. Because of these problems most pulp and paper mills are reluctant to increase white water reuse above the 80% mark for fear of excessive foaming and enhanced corrosion in the paper machine.

The objective of this research was to predict the effect of higher white water resue rates on the foaming tendency and on the corrosivity of white water toward steels used in the paper machine area.

PROCEDURE

Paper pulp and white water from pulp and paper mills making bleached and unbleached kraft pulp were obtained. The pulp was collected after the last washing stage which is just before the pulp enters the paper machine. The white water was taken from the white water recycle line. The pulps were stored at 40°F and the white water samples were stored at room temperature. To simulate in the laboratory various stages of white water recycling, talc, 93% sulfuric acid, sizing chemicals, and paper maker's alum were mixed with distilled water. The chemicals were added to the water at concentrations commomly used in paper mills.[15] Paper pulp was mixed with this water to produce a 1.5% pulp mixture. The pulp was then separated from the water phase by passing the mixture through a Williams sheet mould. The water (called white water) was retained. To insure equilibrium, the white water was recycled through the sheet mould five times with enough fresh pulp added each time to make a 1.5% pulp mixture. The white water generated was then mixed with deionized water at levels calculated to produce from 65% to 95% recycled white water in a 1.5% pulp mixture. The necessary paper machine chemicals were added to the mixture. The mixture was then passed thorugh the sheet mould and the resulting white water samples were characterized.

All analyses were conducted as described in either "Standard Methods for the Examination of Water and Wastewater,"[12] or "Analytical Methods Guide,"[13] The properties chosen to characterize the white water were dissolved solids concentration, acidity, and conductivity. Each analysis was performed in triplicate with the average values reported.

The corrosivity was determined by the Tafel Plot Method[14] while the foaming tendency was measured by the method outlined by Gellman.[10]

RESULTS

White water from operating paper machines in both bleached and unbleached kraft pulp and paper mills were obtained and compared to "simulated" white water generated in the laboratoyr in order to judge the effectiveness of the laboratory simulation process. The percentage of white water recycle in the unbleached kraft mill processes was estimated by pulp mill personnel.

White Water Analysis

The dissolved solids, conductivity and acidity of the actual and simulated white water samples are given in Table 1.

The general trend shown in Table 1 is of rapidly increasing levels of dissolved solids, conductivity and acidity at higher recycle rates. These increases at higher white water recycle rates were expected. Alexander and Dobbins[9] observed for a paper machine that the greater the fraction of water recycled, the higher is the resulting equilibrium concentration. The enrichment factor increases from 2 for 50% recycled to 20 for 95% recycled and was estimated to reach up to 160 for 100% recycle. They predicted that the buildup of dissolved solids rises uniformly up to 95% recycle but above this percentage it would have a sharp rise. As shown in Table 1, for unbleached pulp, the dissolved solids concentration in the simulated white water increased by a factor of 12 in going from 65% to 95% white water recycle. For the bleached pulp the dissolved solids increased by a factor of 8.4 over the same range. Both these increases are similar to the 10-fold increase predicted by Alexander and Dobbins.

The match between actual and simulated white water is fair, with the levels in the actual samples tending to be lower than the simulated samples.

Conductivity and Acidity

The amount of water-soluble ionic substance in white water is found by measuring the conductivity of the water. The acidity is a measure of the acidic compounds present in the white water. As shown in Table 1., the values for the conductivity and acidity for the white water from bleached and unbleached pulp are quite different. The conductivity of bleached pulp is low due to the extensive washing it undergoes while the acidity is high due to residual acidic bleaching chemicals. While the absolute values are different, with both bleached and unbleached pulp white water the conductivity and the acidity both tend to increase rapidly at higher levels of white water recycling. Again, the actual white water samples had lower conductivity and acidity than the simulated white water samples.

Foaming Tendency

The foaming tendency and foam stability for the white water at various recycle rates is given in Table 2. No values for foaming tendency or foam stability were measured for the actual white water samples since defoamers are added in the paper machines, resulting in low foaming values.

The foaming tendency of the bleached pulp white water was considerably less than the foaming tendency of unbleached pulp white water at comparable recycle rates. Apparently the greater acidity of the bleached pulp, as well as the more extensive washing it undergoes, tends to keep the white water produced from foaming an excessive amount.

The approximate level of foaming above which operation of the paper machine is disrupted is 6 mg/l sodium lauryl sulfate or about 30 ml of foam volume per liter of white water. As shown in Table 2, at 80% white water recycle the foam volume is well above the 30 ml/l level for unbleached pulp but below for bleached pulp. Data from pulp and paper mill personnel indicated that usually no defoamer is required in a bleached pulp paper machine but is in an unbleached pulp paper machine.[14,15]

Control of Foaming

To control foaming, both mechanical control and chemical defoamers can be used. Chemical defoamers are generally comprised of hydrocarbons, higher alcohols, complex mixtures of fatty acids and silicons or polyamids.

A defoamer typical of the type used in the paper industry was tested for its effectiveness in foam control using unbleached simulated white water. The results are shown in Figure 1. As the percent white water recylce increases the concentration of defoamer necessary to maintain foam volume below 30 ml/l increases sharply. The amount of demoamer required at 90% white water recycle is about twice the amount required at 85% white water recycle.

Corrosivity - Carbon Steel

A Model M-4100 Potentiodyne Analyzer made by Petrolite Instruments of the Petrolite Corporation was used to determine the uniform corrosion rates of carbon steel specimens in the simulated white water samples. The corrosion rate of carbon steel in white water at 85 to 95% white water recycle is given in Table 3. As shown, the corrosion rate in unbleached pulp white water is relatively low and essentially constant. However, the corrosion rate in bleached pulp white water increases rapidly at higher recycle rates. These corrosion rate results are consistent with the acidity and conductivity data in that the bleached pulp, with greater acidity and conductivity, also was more corrosive.

Corrosivity - Stainless Steel

The high corrosivity of carbon steel in white water is well known. Consequently stainless steels are commonly used in contact with white water. The uniform corrosion rate of 304L stainless steel was measured in the simulated white samples. The corrosion rates were all very small (less than 0.1 mil per year or myp).

Since the change in uniform corrosion rates for stainless steel was so small it was decided that to study the effect of increased white water recycling on the corrosion rate a statistical program that related the uniform corrosion rates (dependent variable) to certain ion concentrations (independent variables) of the simulated white water should be used. Five independent ions were chosen to simulate white water based their potential for the corrosion of stainless steel. These were: barium, aluminum, chloride, sulfate, and sodium. Using the Alexander-Dobbins model[9] ranges of ion concentrations were calculated for 80% to 92% white water recycle. A coding system for the independent variables by Cochran and Cox[16] gave ion concentrations as shown in Table 4. The coding systems required thirty-two observations for a 1/2 replicate of a 2^5 factorial plus star design plus six points in the center. Each corrosion test was completed in duplicate.

The 304L stainless steel test specimens were heat-treated to insure the correct crystalline structures before corrosion testing. One test coupon was heated to a temperature of 1750°F for a period of one hour and then air quenched to obtain a completely annealed sample. The second test coupon was heated to a temperature of 1150°F for a period of one hour and then air quenched for a sensitized sample.

A Second Order Response Surface Analysis was used to fit the data to a second order polynomial equation with linear, quadratic and two-factor interaction terms. The arithmetic mean uniform corrosion rate was 0.073 mpy with a standard deviation of 0.012 mpy. The R-squared value for the data correlation was 0.080 indicating that there was no correlation between the various ion concentrations on the rate of uniform corrosion of 304L stainless steel. The uniform corrosion rates measured at each observation point are given in Table 5. While other types of corrosion of stainless steel, such as pitting or stress corrosion, may be enhanced at higher white water recycle rates, the data clearly shows that the uniform corrosion rate of 304L stainless steel is not significantly increased by increasing the percentage of white water recycled from 80% to 92%.

SUMMARY

White water was produced in the laboratory under simulated recycling conditions which had properties similar to white water taken from paper machines operating at comparable recycle rates. It was found that as the percentage of white water recycled is increased that the dissolved solids concentration, conductivity, and acidity of the white water rapidly increases.

Foaming rapidly increases as the percentage of white water recycled is raised. In unbleached pulp mills excessive foaming occurs at about 70% white water recycle. In bleach pulp mill excessive foaming will not occur until the percentage of white water recycle excedes about 82%. While foaming can be controlled by the addition of defoamers, as the percentage of white water recycled is increased, the concentration of defoamer required rapidly increases.

The corrosivity of carbon steel in white water tends to increase at higher white water recycle levels. However, the uniform corrosion rate of 304L stainless steel was not significantly affected by higher white water recycle rates. While other types of corrosion, such as pitting and stress corrosion, may become more severe at higher white water recycle levels, the uniform corrosion of 304L stainless steel is not changed.

ACKNOWLEDGEMENTS

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Table 1. Dissolved Solids, Conductivity and Acidity of White Water at Various Recycle Rates

Recycle Rate %	Dissolved Solids mg/1	Conductivity m-Ohm/cm	Acidity mg/1 $CaCo_3$
UNBLEACHED PULP WHITE WATER			
65	0.10	740	18
75	0.32	800	22
80	0.60	870	30
80*	0.54	790	30
85	0.80	950	35
90	0.93	1070	40
95	1.20	1220	47
BLEACHED PULP WHITE WATER			
65	0.12	550	59
75	0.45	600	65
78*	0.57	595	64
80	0.65	625	73
85	0.79	725	80
90	0.85	815	87
95	1.01	950	98

* Actual mill samples of white water.

Table 2. Foaming Tendency and Foam Stability of White Water at Various Recycling Rates

Recycle Rate %	Foam Sigma (min)*	Foam Concentration (mg/l)**	Foam Volume (ml/l)
		Unbleached Pulp	
65	0.22	4	20
75	0.38	8	40
80	0.56	12	55
85	0.80	15	80
90	0.88	16	120
95	1.00	18	160
		Bleached Pulp	
65	0.05	0.1	5
75	0.10	0.50	10
80	0.25	5	25
85	0.35	7	35
90	0.48	11	50
95	0.60	13	60

* Life time of an average bubble

** Equivalent concentration in reference to sodium laurly sulfate

Table 3. Corrosivity of Recycled White Water with Carbon Steel

White Water	Recycle Rate (%)	Corrosivity (mil/yr)
Unbleached	85	10.9
	90	18.4
	95	11.8
Bleached	85	125.0
	90	275.0
	95	428.0

Table 4. Coding System for a 5 X-Variables Plan with 32 Observations (1/2 Replicate of a 2^5 Factorial + Star Design + 6 Points in the Center)

	Variable Code (ion concentrations in ppm)				
Ions	−2	−1	0	+1	+2
Chloride	7.0	9.6	12.2	15.1	17.5
Sulfate	910.0	1252.0	1593.0	1934.0	2275.0
Sodium	210.0	289.0	368.0	446.0	525.0
Barium	0.100	0.128	0.175	0.210	0.250
Aluminum	1.25	1.72	2.19	2.66	3.13

* example observation code for 5 ions: 1,1,-1,-1,1

Table 5. Uniform Corrosion Rates of Annealed and Sensitized 304L Stainless Steel Measured in Statistical Program

Observation No.	Run No.	Annealed sample,mpy	Sensitized sample, mpy	pH	Conductivity millimhos/cm
1	1	0.0539	0.0566	2.09	5.38
	2	0.0458	0.0620	2.09	5.30
2	1	0.0674	0.0593	2.10	5.40
	2	0.0647	0.0809	2.06	5.48
3	1	0.0674	0.0593	1.78	8.71
	2	0.0566	0.0647	1.82	8.91
4	1	0.0620	0.0593	2.01	8.71
	2	0.0620	0.0539	1.89	8.91
5	1	0.0593	0.0539	2.59	4.06
	2	0.0593	0.0620	2.46	4.24
6	1	0.0512	0.0539	2.61	4.06
	2	0.0593	0.1078	2.46	4.00
7	1	0.0566	0.0520	1.99	7.47
	2	0.0593	0.1132	2.01	7.31
8	1	0.0488	0.0647	1.96	7.57
	2	0.0593	0.1132	1.99	7.36
9	1	0.0485	0.0728	2.12	5.38
	2	0.0593	0.1348	2.15	5.22
10	1	0.0916	0.0701	2.12	5.38
	2	0.0593	0.1240	2.16	5.30
11	1	0.0809	0.0647	1.83	8.50
	2	0.0593	0.1186	1.90	8.71
12	1	0.0647	0.0701	1.83	8.81
	2	0.0593	0.1024	1.83	8.81
13	1	0.0539	0.0701	2.41	3.98
	2	0.0539	0.0863	2.46	4.02
14	1	0.0566	0.0647	2.43	4.41
	2	0.0593	0.0383	2.45	4.06
15	1	0.0811	0.0620	1.95	7.47
	2	0.0512	0.0458	2.02	7.47
16	1	0.0647	0.0593	1.94	7.47
	2	0.0485	0.0431	1.99	7.53
17	1	0.0728	0.0566	2.08	6.78
	2	0.0593	0.0485	2.06	6.33
18	1	0.0647	0.0566	2.05	6.38
	2	0.0566	0.0404	2.06	6.43

Table 5. Continued

Observation No.	Run No.	Annealed sample,mpy	Sensitized sample,mpy	pH	Conductivity millimhos/cm
19	1	0.0647	0.0916	2.85	2.57
	2	0.0970	0.0916	2.81	2.49
20	1	0.0539	0.0701	2.51	3.12
	2	0.1051	0.0970	2.47	3.13
21	1	0.0701	0.0701	2.58	2.98
	2	0.0890	0.0782	2.55	2.87
22	1	0.0539	0.0916	2.73	2.70
	2	0.0863	0.0755	2.73	2.60
23	1	0.0593	0.0728	2.66	2.91
	2	0.0916	0.0755	2.64	2.83
24	1	0.0647	0.0916	2.65	2.86
	2	0.0863	0.0863	2.62	2.84
25	1	0.0529	0.0755	2.67	2.85
	2	0.0863	0.0647	2.64	2.78
26	1	0.0647	0.0701	2.65	2.79
	2	0.0916	0.0701	2.60	2.91
27	1	0.0647	0.0701	2.65	2.85
	2	0.0943	0.0701	2.63	2.85
28	1	0.0647	0.0647	2.64	2.70
	2	0.1024	0.0593	2.61	2.81
29	1	0.0674	0.0809	2.65	2.85
	2	0.0701	0.0701	2.60	2.79
30	1	0.0674	0.0701	2.64	2.75
	2	0.0809	0.0755	2.61	2.82
31	1	0.0647	0.0863	2.65	2.85
	2	0.0809	0.0782	2.62	2.81
32	1	0.0647	0.0701	2.65	2.86
	2	0.0809	0.0647	2.62	2.84

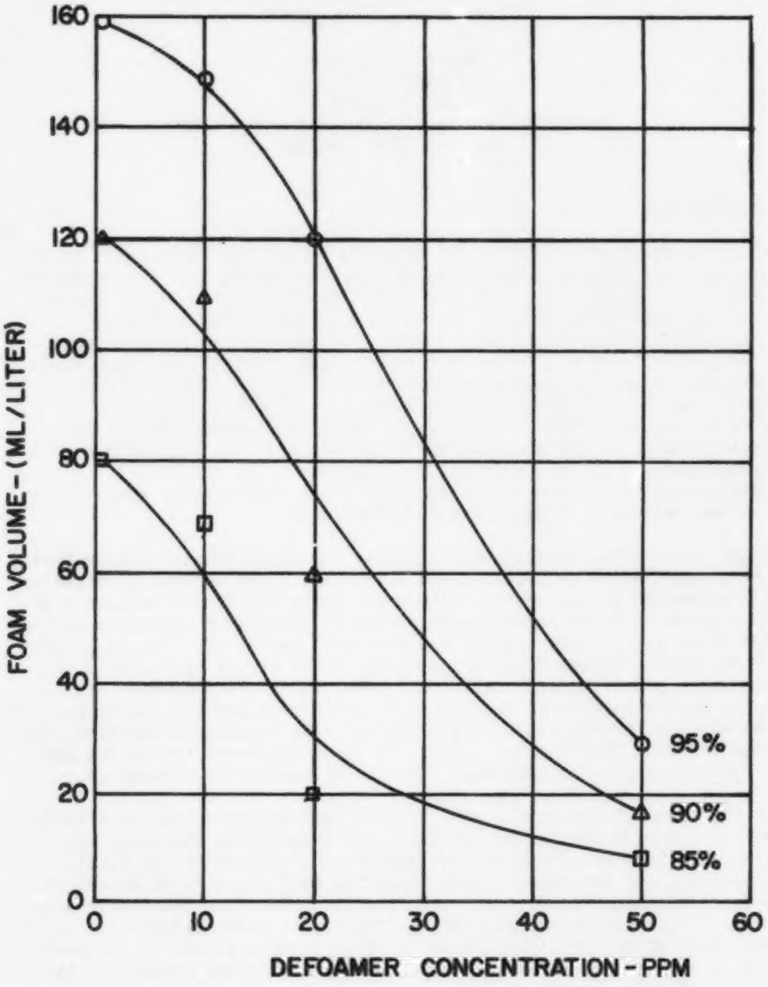

Figure 1: Defoamer Concentration v. Foam Volume in Unbleached White Water at Various Percent Recycling

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A WET END OPTIMIZATION STRATEGY FOR TOTAL WATER REUSE

Michael D. Strutz
Environmental Engineer
U.S. Environmental Protection Agency
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

Allan M. Springer
Assistant Professor
Miami University
Department of Paper Science and Engineering
Oxford, Ohio 45056

INTRODUCTION

The pulp and paper industry is currently facing the implementation of stricter effluent limitations being proposed by the U.S. Environmental Protection Agency. By 1984, the industry will be required to reduce their effluent discharge of Biochemical Oxygen Demand and Total Suspended Solids from current levels. In meeting the previous Best Practicable Treatment technology regulations, industry environmentalists recognized the cost-effectiveness of in-process recycle/reuse techniques for reducing effluent loadings. In fact, many mills in several subcategories of the industry have implemented total water reuse strategies for the complete elimination of their discharge. It is the purpose of this research to investigate the possibility of total water reuse in the non-integrated fine paper subcategory, specifically the manufacture of a high opacity offset grade.

Miami University investigated a totally closed whitewater system during the production of an offset grade in 1977(1). The buildup of dissolved and suspended solids in the whitewater system was monitored over a 96 hour period. Paper samples were collected at regular intervals during the trial and various quality analyses were performed. The study concluded that problems would arise in the areas of sizing, brightness reversion and first pass retention. The authors recommended that these problems could be controlled by optimizing wet end chemistry, thereby controlling first pass retention. By computer simulation, they observed that this strategy would, in turn, eliminate the sizing and brightness reversion problems. The key is controlling retention.

In the study of retention, many authors have observed adverse effects associated with the buildup of dissolved organic and inorganic substances. Swanson, Stratton, and Huettner(2), Lindstrom, et al(3), Arnson(4), and Penniman(5) have shown how small amounts of dissolved organic material can decrease the effectiveness of cationic retention aids. These dissolved materials can be lignin, hemicelluloses, fatty and resin acids, or lignosulfonic acids. Their presence in the papermaking system causes a higher cationic demand thereby increasing the amount of cationic retention aid required to reach optimum flocculation. Alexander and Dobbins(6), and Springer, Scott and Heller(1) have shown how dissolved inorganic materials buildup in closed whitewater systems. You would suspect that, according to classical electrokinetic theory, this phenomenon would decrease the amount of cationic retention aid required to reach optimum flocculation. In fact, Unbehend(7) showed that improved retention can be obtained using monovalent and divalent cations, such as sodium chloride and magnesium chloride. The fact that alum (aluminum sulfate) is the predominant cationic coagulent used in the industry agrees with the Schulze-Hardy rule which states that the amount of counterions necessary to eliminate a net repulsion is proportional to the inverse sixth power of its valence. Therefore, much less alum is required to produce similar coagulating effects.

Dissolved organic and inorganic materials in the system can be considered controlled or uncontrolled variables from a process control standpoint. Those materials coming into the system from the raw water or raw materials are generally considered not controllable. A process control variable such as alum, however, can be controlled or uncontrolled. That is, if the concentration of alum in the system is not closely watched, a situation may develop where retention is adversely affected. Avery(8) demonstrated this and found that by decreasing the alum concentration in a system using cationic starch retention on the machine was significantly improved. This same phenomenon has also been shown to occur with synthetic organic retention aids. Excessive amounts of these retention aids in the system will also cause stock dispersion and, hence, poorer retention(9).

It becomes increasingly clear, from the previous discussion, that the control of retention will become more complicated in a totally closed system. In the 1977 machine trial at Miami University, dissolved organic and inorganic solids, as well as alum, continued to buildup during the run. Based on this information, the objectives of the current study are: to determine how the alum demand changes under wet end conditions found in a totally closed system; to determine if the higher concentrations of dissolved organic and inorganic solids will interfere with the alum titration measurement technique; and to demonstrate on-line alum control as a technique to improve retention in a totally closed system.

LABORATORY RESULTS

Phase I - Bench Scale Retention Analyses

A series of experiments was performed to observe the effects of dissolved organics, dissolved inorganics, alum, and shear on the retention of fines in a vaned Dynamic Retention/Drainage Jar(10). A 76 micron, 14.5% open area electrodeposited nickel screen was used in the jar. The furnish used is shown in Table 1. A 3^3 factorial design was used at the low shear level, 300 revolutions per minute (r.p.m.), and two 2^3 factorial experiments were performed at the medium and high shear levels (600 and 900 r.p.m.). All experiments were performed at room temperature and pH 4.50 ± 0.02 units. pH was adjusted using HCl or NaOH. The levels for the independent variables are shown in Table 2. Dissolved inorganics were treated cummulatively as the total of various levels of calcium, magnesium, manganese, and iron derived from observations during a previous totally closed machine run. The individual levels for the dissolved inorganics are shown in Table 3. The dissolved organics used in the study were obtained by beating bleached kraft fiber, filtering off the solids, and concentrating the dissolved organic material in the filtrate using reverse osmosis.

The levels of dissolved organics used correspond approximately to levels of volatile dissolved solids measured during a previous closed machine run on this paper grade.

Effect of Organics Figure 1 shows the data plotted at the low dissolved inorganic level. It shows the negative effect of increasing concentrations of dissolved organics on retention. At 1% alum, 300 r.p.m., and 1100 ppm organics, the decrease in retention was approximately 24%. The effect at 600 r.p.m. was about 6% and at 900 r.p.m. there was no significant decrease in retention (95% confidence limits for all the data was ± 3.4%). The fines retention at 600 r.p.m. was 35%, while at 900 r.p.m., it was about 25%.

Effect of Inorganics Figure 2 shows two distinctly different effects from increasing levels of dissolved inorganics. At the low dissolved organic level, an increase in the level of dissolved inorganics causes a decrease in retention, while at the medium and high levels, adding the dissolved inorganics causes an increase in retention. Although the zeta potential results do not correlate perfectly with the results obtained, a general relationship can be observed. That is, depending on the initial zeta potential of the system, the addition of dissolved organic or inorganic compounds may cause either an increase or decrease in retention. Adding dissolved inorganics to a system exhibiting a positive zeta potential will cause a decrease in retention while adding them to a system exhibiting a negative zeta potential will cause an increase in retention. This would agree with classical electrokinetic theory which states that maximum coagulation occurs at zero zeta potential.

Effect of Alum Figure 1 illustrates how the alum demand of the system changes according to the initial levels of dissolved organic material. The most significant effect is at the low shear, low inorganic, and high organic level. An increase in the alum level from 1% to 3% increased retention approximately 20%. It is apparent that the organic material which is anionic in character is causing a significant alum demand. By adjusting the alum concentration, the negative effects of this material can be minimized at low shear levels.

Effect of Shear The experiments described above were conducted at three levels of shear for the purpose of seeing how the effects of these variables on retention will vary on different machines in the industry. It is apparent that shear plays a dominant role in the retention mechanism for this particular system. At the intermediate and high shear levels, the effects of the independent variables were dampened out. As was expected, the "soft" flocs formed were not very resistant to shear. Retention dramatically decreased with increasing shear.

Zeta Potential/Retention Correlation In order to obtain a better idea of how zeta potential and retention correlate, an experiment was conducted to allow alum to vary over a much wider range while keeping all other variables constant. In addition to monitoring fines retention, the retention of dissolved organics (measured as Total Organic Carbon) and ash was also observed. The results are shown in Figure 3.

The figure illustrates several important points. First, retention of fines and ash did peak at zero zeta potential at an alum concentration of approximately 10%. Alum concentrations above 10% tended to decrease retention. At 30% alum, retention of fines had dropped off approximately 15% from the peak while ash retention of fines had dropped off close to 20%. Second, while retention peaked at 10% alum and zero zeta potential, all of the subsequent alum levels above 10% also exhibited zero zeta potential. Separate experiments were conducted to investigate this zeta potential phenomenon and are discussed in the next section. The third point is that the level of TOC in the retention/drainage jar filtrate steadily declined with increasing alum concentrations. This would indicate that the retention of dissolved organic material steadily improves at higher alum concentrations, while the retention of fines and ash decreases. It is apparent from a papermaking point of view that the retention of fines and ash takes presidence and alum should be controlled on that basis.

Effect of Dissolved Organics on Zeta Potential In the previous experiments, many of the data points, particularly the points at the intermediate and high dissolved organic levels, exhibited zero zeta potential. Separate experiments were conducted to determine if this phenomenon was characteristic of a system containing quantities of dissolved organic material. Various quantities of this material were added to a typical furnish, the fiber was filtered off, and the zeta potential of the fines determined. Figure 4 shows the results of this experiment which was conducted with distilled water. Figure 5 shows the results of the same experiment conducted with tap water.

In both cases, tap water and distilled water, similar curves were obtained using alum and no organic material. The charge on the particles changed from negative to positive at approximately 2% alum. The curve peaked at about +15 mV zeta potential then steadily decreased with further increases in alum concentration. This phenomenon has been previously illustrated in the literature(11) and has been attributed to formation of aluminum hydroxide and the increasing sulfate ion build-up.

Figure 4 also illustrates that the increase in the dissolved organic material in the sample has the effect of suppressing the zeta potential and increasing the alum demand, i.e., the amount of alum required to reach zero zeta potential. The suppression of the zeta potential can also be seen in Figure 5. This phenomenon seems to be characteristic of the organic material and not of aluminum hydroxide formation and sulfate ion build-up. There seems to be a point around 200 ppm of organics where the charge on the particles will not reverse, i.e., will not become positive. It is theorized that a neutrally charged organic polymer is being formed and is coating the particle surface. This effect, coupled with neutrally charged aluminum hydroxide formation and sulfate ion build-up, is creating a stable, neutrally charged structure resistent to charge reversal. It is acting in a similar manner in which starch forms a protective colloid.

These results make one question the usefulness of zeta potential even in this purely ionic system. It would be beneficial at low alum levels, i.e., below the iso-electric point, but lose significance as a control tool at higher levels.

Phase II - Alum Titration Method Interference Analysis

The series of experiments conducted during Phase I illustrated the fact that the alum demand of the system changes according to the chemistry of the wet end, at least at the low shear levels. This observation would, therefore, necessitate the use of an on-line alum control system to continuously vary the alum concentration in proportion to its demand for optimum retention. Avery(8) discussed the use of an alum titration procedure which can be used to effectively monitor the alum concentration in the system. In addition, a continuous on-line alum monitoring and control system is currently being marketed which is based on the same principle. The technique makes use of a fluoride specific ion electrode to measure the residual fluoride in solution after the reaction of a 0.1M sodium fluoride titrant with the alum in a sample from the paper machine. It was hypothesized that any compound in the system besides alum might present the possibility of interfering with the titration either by reacting with the fluoride (a positive interference), or by reacting with the alum and making it inaccessible to the fluoride (a negative interference). Therefore, it is the objective of this phase to determine whether or not the concentrations of dissolved inorganic and organic compounds expected to be found in totally closed systems would interfere with the titration.

A series of simple comparison experiments were conducted holding the alum concentration constant at a low level (100 ppm) and the suspected interfering compounds at high levels. The interferences investigated were organics, iron, calcium, magnesium and manganese. Each experiment was replicated five times.

Table 4 shows the average difference associated with each variable. In the case of the organic concentrate and iron, a positive interference of 19 ppm and 5 ppm was observed. If both were present, an interference of 24 ppm as alum may result from their presence in the sample. Therefore, if this sample had been taken from the headbox of machine operating of 0.5% consistency, the titration would have predicted approximately one half of a percent more alum than was actually present. The interference due to iron was due to the greater affinity to fluoride having a higher charge density than the other inorganic ions evaluated. The organic concentrate used for the study also contained a substantial quantity of metal ions, especially calcium, which would possible explain the positive interference which it exhibited.

From a process control point of view, the titration is sufficiently accurate to enable monitoring and control of alum, based on the parameters used in this study. The papermaker should be aware of possible interferences in their particular system and screen any additives for possible interference to allow proper interpretation of results from the titration.

SUMMARY AND CONCLUSION

In developing a wet end optimization strategy for total water reuse, a papermaker should consider how a particular retention control strategy will ultimately affect paper quality and machine runability. Porwal(12) has shown the contribution of alum to scale problems on machine wires. Other researchers have shown how excessive alum concentrations can adversely affect the action of synthetic organic retention aids. This study has demonstrated how excessive alum concentrations alone will adversely affect retention. Work is continuing at Miami University on how excessive alum concentrations will affect paper quality.

From a retention point of view, the following conclusions can be drawn from this study:

1. In a totally closed system, some means of controlling the alum concentration will be necessary. This will involve measuring the concentration of alum and making adjustments through a feedback control system. The optimum alum level required will vary with system conditions.
2. In a totally closed system, the build-up of dissolved organic and inorganic compounds may or may not adversely affect retention depending on the relative concentration of each. In this study, the effect of the organics on retention was much greater than that of the inorganics. The negative effects of increasing organic concentrations can be overcome by properly adjusting the alum level. The level of organic material should be monitored and the alum level adjusted accordingly to achieve optimum retention.
3. When using zeta potential as a retention optimization parameter, the papermaker should be careful not to relate a zero reading with optimum conditions in the wet end. The level of dissolved pulp-derived material has a significant effect on the measurement of that parameter and may cause a false interpretation of where the optimum alum concentration occurs.
4. It appears that at higher shear levels, polymer retention aids will be required to achieve satisfactory retention. Computer simulation of the data collected during the 1977 machine trial at Miami University predicted 25% ash retention as being satisfactory. Ash retention levels at 600 and 900 r.p.m. during the current study were below 25%.

Using this information, machine trials, utilizing a low shear machine, will be conducted at Miami University to work out the mechanics of an alum control strategy and determine if retention and paper quality can be maintained at satisfactory levels. Information gained during these trials will be available at a later date.

MATERIAL AND METHODS

Dissolved Organics Generation

Ten kilograms of bleached kraft pulp (60% hardwood, 40% softwood) was beaten in 225 liters of distilled water to 150 Canadian Standard Freeness (CSF). The pH in the beater was adjusted with HCl to approximately 4.60. The contents of the beater were vacuum filtered through a nylon mesh bag and Whatman No. 1 filter paper with the filtrate collected in a stainless steel drum. This procedure was replicated four times during the study to provide sufficient quantity of organics. An average of 151.41 liters was recovered through the filtration process. The dissolved material in the filtrate represented, on the average, 81.7 ppm as Total Organic Carbon. Based on the weight of the pulp, approximately 0.18% was solubilized during the beating process.

Concentration of the dissolved organic material in the filtrate was accomplished by reverse osmosis. An Osmonics, In. 97E unit using three membrane modules operated in series was used. Each module contained 1.77 square meters of cellulose acetate membrane. The unit operates at permeate rate of 11.67 cubic centimeters per second (CCS) and at a concentrate rate of 37.32 CCS at an operating pressure of approximately 15 atmospheres. Based on TOC analyses of the raw filtrate sample and the concentrate, the unit achieved an average recovery of organics of 75.4%.

The concentrate from the unit was lyophilized to dryness. Chemical analyses of the organic material were performed by PEDCo Environmental, Inc. and the Institute of Paper Chemistry. Results of the analyses are shown in Table 5. The data shows that carbohydrates represent approximately 23% by weight of the identified organic material. Xylans account for over 80% of this fraction. Uronic acids are the next largest fraction at 2.78% followed by acid insoluble lignin and acid soluble lignin at approximately 2% each. Of the inorganic material identified, calcium represents the largest fraction at 6.3% by weight followed by sodium at 3%. These two elements represent almost 85% of the identified inorganic material in the sample. About 40% of the organic material and 19% of the inorganic material remains unidentified. Additional analytical work is being performed to account for this material.

DISSOLVED INORGANICS

Analytical reagent grade chemicals were used to make up stock solutions to supply the concentration of calcium, magnesium, manganese, and iron used in the study. Calcium chloride ($CaCl_2.2H_2O$), magnesium chloride ($MgCl_2.6H_2O$), manganous chloride ($MnCl_2.4H_2O$), and ferric chloride ($FeCl_3.6H_2O$) were used.

The alum used was analytical reagent grade ($Al_2(SO_4)_3.16H_2O$). A freshly prepared solution was used for each data point.

FINES FRACTIONATION AND RETENTION

TAPPI Method T261pm-79 was followed for performing all fines fractionations and retention procedures. A Dynamic Retention/Drainage Jar, purchased for Paper Research Materials, Inc., was used throughout the study.

ALUM TITRATION

Avery(8) described a procedure for determining the alum concentration in a wet end sample using a fluoride specific ion electrode and an expanded scale pH meter. This procedure was used during the study.

ZETA POTENTIAL

A model 1133 instrument, manufactured by Zeta-meter Inc., was used for all zeta potential measurements.

ACKNOWLEDGEMENTS

This project was made possible through a grant from the U.S. Environmental Protection Agency's Innovative Research Program. Special thanks are extended to Stephen Gage, Steven Reznek, Morris Levin, David Stephan, William Cawley, Eugene Berkau, and Kirk Willard for their assistance in approving this project. The cooperation of Frederick Kopfler, Paul Ringhand, and Donald Mitchell, of EPA's Health Effects Research Laboratory in generating the organics used in the study was gratefully appreciated. The continuing advice and support of Victor Jelen and Paul de Percin of EPA's Food and Wood Products Branch was most helpful throughout the course of the project.

Miami University's Department of Paper Science and Engineering was the site for this research project. Many thanks to C. Edwin Brandon and staff without whose help this project would not have been possible.

A special note of thanks to William Scott of Champion International Corporation whose helpful technical assistance was willingly given and was most gratefully appreciated.

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory-Cincinnati, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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TABLE 1

EXPERIMENTAL FURNISH

COMPONENT	%(Wt.)
Bleached Kraft-Hardwood	48
Bleached Kraft-Softwood	32
Kaolin Clay	20
Rosin Size	0.5
Furnish beaten to 350 CSF in distilled water	
Fines Fraction of Furnish	35

TABLE 2

INDEPENDENT VARIABLES

Variable	Low	Medium	High
Dissolved Organics* (ppm)	0	550	1100
Dissolved Inorganics**(ppm)	0	94.5	189
Alum (%)	1	2	3
Shear (r.p.m.)	300	600	900

* This represents the actual quantity of dissolved organic concentrate added to each sample. See chemical analyses for characterization of these materials.

**See Table 3 for individual levels of calcium, magnesium, manganese, and iron.

TABLE 3

DISSOLVED INORGANIC LEVELS

Inorganic	Low	Medium	High
Iron, as Fe^{3+}(ppm)	0	7	14
Calcium, as Ca^{2+}(ppm). . .	0	65	130
Magnesium, as Mg^{2+}(ppm). .	0	20	40
Manganese, as Mn^{2+}(ppm). .	0	2.5	5

TABLE 4

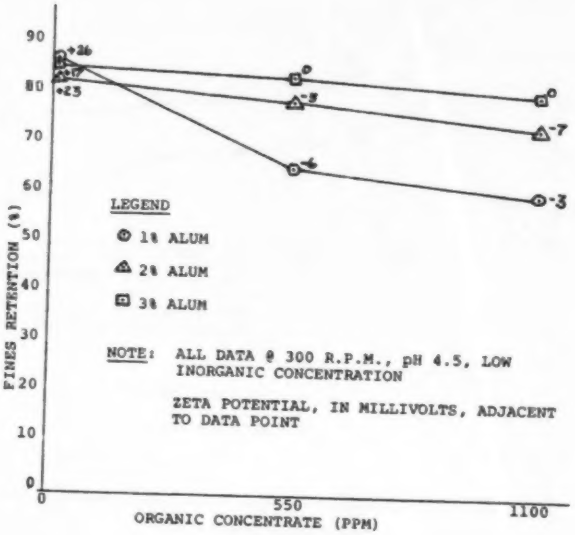
ALUM TITRATION INTERFERENCES

Substance (ppm)	Average Difference	
	Volume Titrant(mls)	Alum Equivalent(ppm)
Organic concentrate (1100)	+0.138	+19
Iron (14)	+0.034	+5
Calcium (130)	0	0
Magnesium (40)	0	0
Manganese (5)	0	0

TABLE 5

ORGANIC CONCENTRATE ANALYSIS

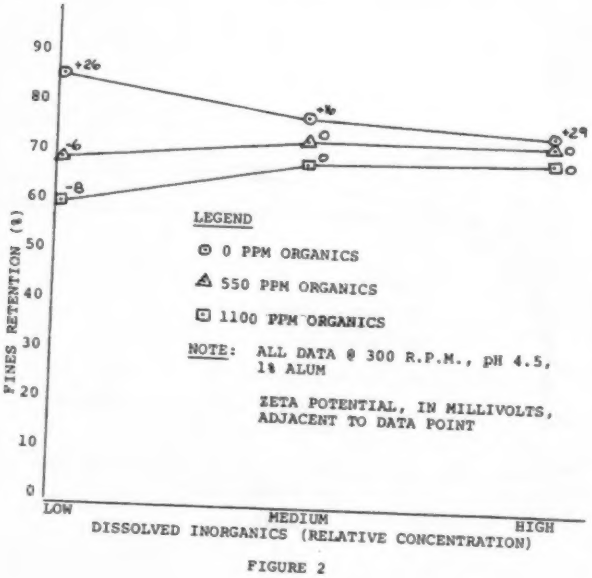
Compound	Weight(%)
Acid Insoluble (Klason) Lignin	2.085
Acid Soluble Lignin	1.950
Total Carbohydrate	22.750
Araban	1.150
Xylan	18.400
Mannan	0.650
Galactan	1.000
Glucan	1.550
Uronic Acid	2.780
Oleic Acid	0.003
Linoleic Acid	0.001
Tetrachloroguaiacol	0.033
Chloride	0.192
Sulfate	0.020
Aluminum	0.301
Calcium	6.300
Iron	0.394
Magnesium	0.288
Manganese	0.031
Sodium	3.030
Ash (550°C)	30.100
Unidentified	59.842



NOTE: ALL DATA @ 300 R.P.M., pH 4.5, LOW INORGANIC CONCENTRATION

ZETA POTENTIAL, IN MILLIVOLTS, ADJACENT TO DATA POINT

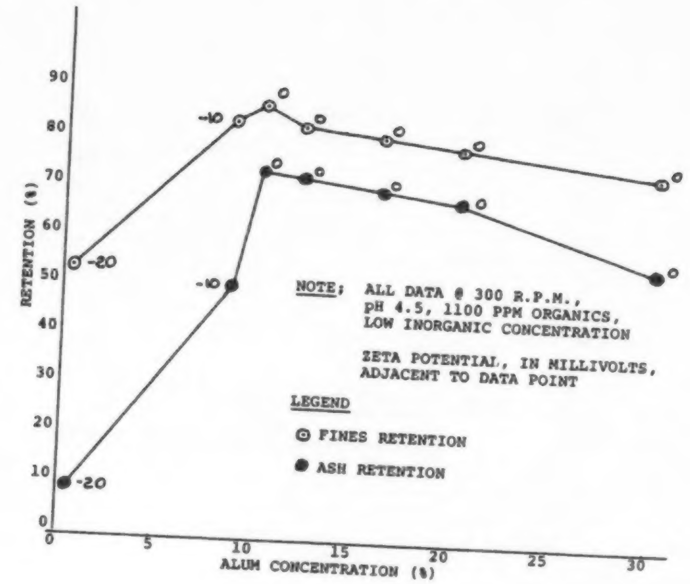
FIGURE 1



NOTE: ALL DATA @ 300 R.P.M., pH 4.5, 1% ALUM

ZETA POTENTIAL, IN MILLIVOLTS, ADJACENT TO DATA POINT

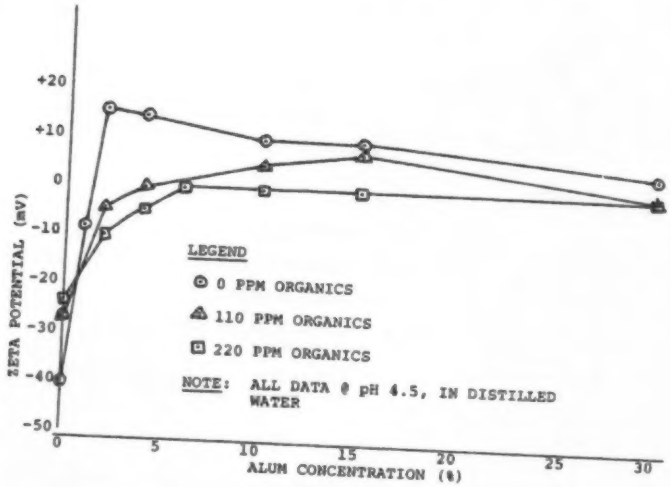
FIGURE 2



NOTE; ALL DATA @ 300 R.P.M., pH 4.5, 1100 PPM ORGANICS, LOW INORGANIC CONCENTRATION

ZETA POTENTIAL, IN MILLIVOLTS, ADJACENT TO DATA POINT

FIGURE 3



NOTE: ALL DATA @ pH 4.5, IN DISTILLED WATER

FIGURE 4

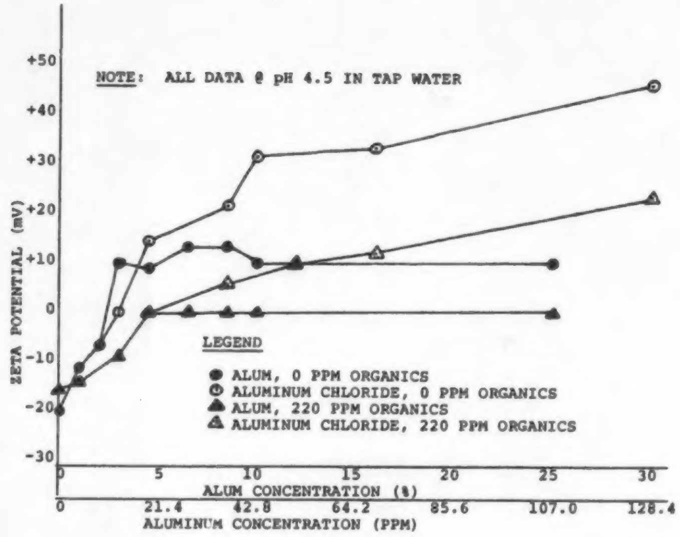
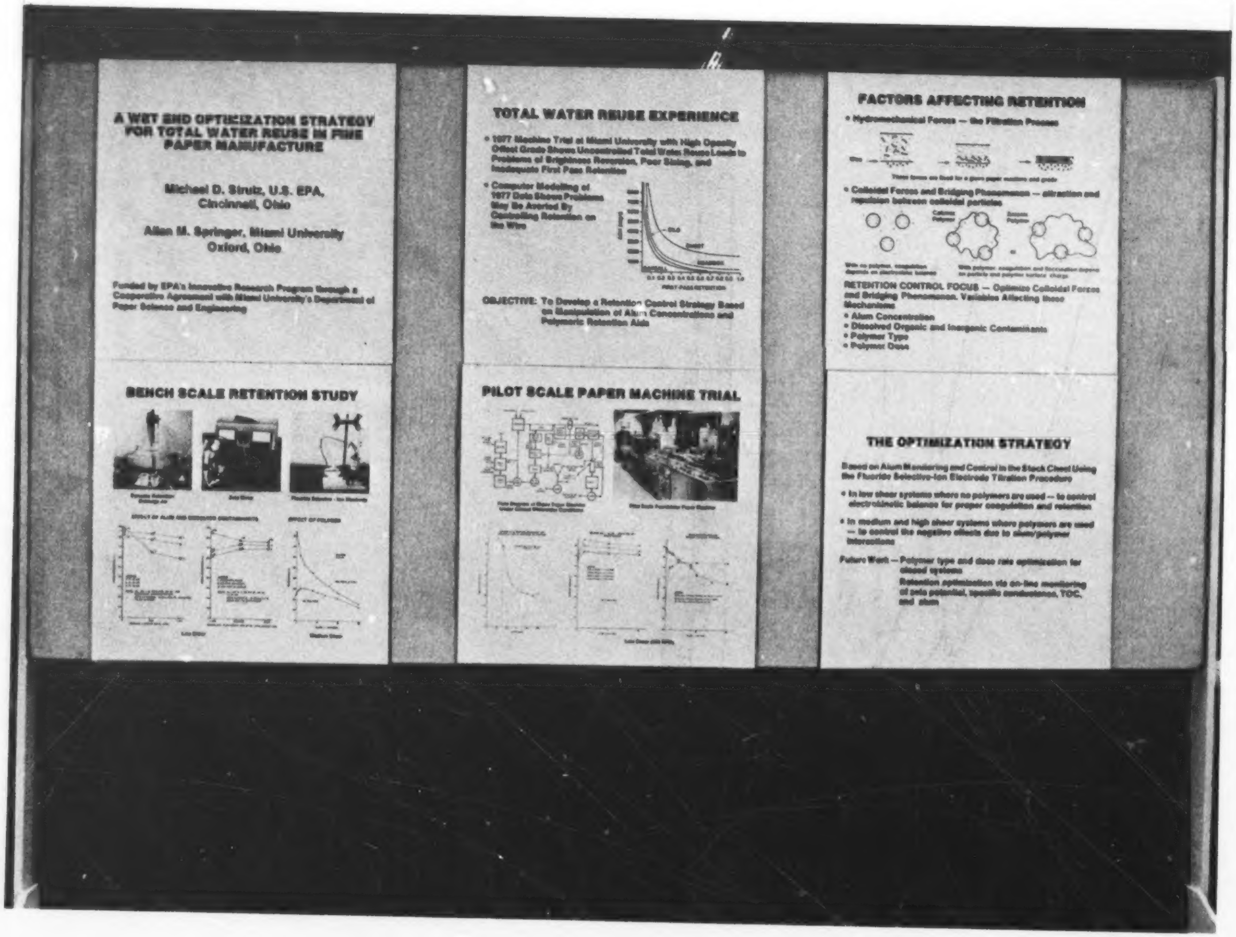

NOTE: ALL DATA @ pH 4.5 IN TAP WATER
ZETA POTENTIAL (mV)
+50
+40
+30
+20
+10
0
-10
-20
-30
LEGEND
● ALUM, 0 PPM ORGANICS
⊙ ALUMINUM CHLORIDE, 0 PPM ORGANICS
▲ ALUM, 220 PPM ORGANICS
△ ALUMINUM CHLORIDE, 220 PPM ORGANICS
0
5
10
15
20
25
30
ALUM CONCENTRATION (%)
0
21.4
42.8
64.2
85.6
107.0
128.4
ALUMINUM CONCENTRATION (PPM)

FIGURE 5



A WET END OPTIMIZATION STRATEGY FOR TOTAL WATER REUSE IN FINE PAPER MANUFACTURE

Michael D. Strutz, U.S. EPA,
Cincinnati, Ohio

Allen M. Springer, Miami University
Oxford, Ohio

Funded by EPA's Innovative Research Program through a Cooperative Agreement with Miami University's Department of Paper Science and Engineering

BENCH SCALE RETENTION STUDY

TOTAL WATER REUSE EXPERIENCE

- 1977 Machine Trial at Miami University with High Opacity Offset Grade Shows Uncontrolled Total Water Reuse Leads to Problems of Brightness Reversion, Poor Sizing, and Inadequate First Pass Retention
- Computer Modelling of 1977 Data Shows Problems May Be Averted By Controlling Retention on the Wire

OBJECTIVE: To Develop a Retention Control Strategy Based on Manipulation of Alum Concentrations and Polymeric Retention Aids

PILOT SCALE PAPER MACHINE TRIAL

FACTORS AFFECTING RETENTION

- Hydromechanical Forces — the Filtration Process

These forces are fixed for a given paper machine and grade

- Colloidal Forces and Bridging Phenomenon — attraction and repulsion between colloidal particles

With no polymer, coagulation depends on electrokinetic balance

With polymer, coagulation and flocculation depend on particle and polymer surface charge

RETENTION CONTROL FOCUS — Optimize Colloidal Forces and Bridging Phenomenon. Variables Affecting these Mechanisms

- Alum Concentration
- Dissolved Organic and Inorganic Contaminants
- Polymer Type
- Polymer Dose

THE OPTIMIZATION STRATEGY

Based on Alum Monitoring and Control in the Stock Chest Using the Fluoride Selective-Ion Electrode Titration Procedure

- In low shear systems where no polymers are used — to control electrokinetic balance for proper coagulation and retention
- In medium and high shear systems where polymers are used — to control the negative effects due to alum/polymer interactions

Future Work — Polymer type and dose rate optimization for closed systems
Retention optimization via on-line monitoring of zeta potential, specific conductance, TOC, and alum

PB82-223512

EXAMINING THE OPPORTUNITIES FOR RECYCLE AND REUSE OF CHEMICAL INDUSTRY WASTEWATERS

Ronald J. Turner
U.S. EPA
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

ABSTRACT

Water use practices in industry have undergone radical changes in recent years. Early water pollution control measures focused on end-of-pipe treatment to reduce the suspended solids and oxygen-demanding organics from industrial discharges. Recent legislation, which recommends a goal of zero discharge of pollutants, prompted this investigation of recycle and reuse opportunities by the EPA's Office of Research and Development. Segments of the Organic Chemical Industry may derive benefits from development of a water conservation program which concomitantly reduces the organic concentrations in the final wastewaters and reduces treatment costs. A discussion of acetaldehyde is presented herein to illustrate the approach that was used to evaluate the reuse/recycle potential for all of a series of organic chemical production processes.

INTRODUCTION

EPA's Office of Research and Development (ORD) sponsored a study to develop technical information on the potential for recycle and reuse of organic chemical industry wastewaters and to determine if real opportunities exist for reuse/recycle.

The second largest manufacturing water users are currently the chemical and allied products industries with approximately 26 percent of the total manufacturing water intake in 1975 of 51 billion gallons per day. About one-half of the water intake by this industry has been for industrial organic chemicals. Recycling is expected to reduce water withdrawals for the chemicals and allied products industries in the year 2000 from 13.5 billion gallons per day to 5.2 billion gallons per day, while daily consumption increases by over 300 percent from 1.3 billion gallons to 4.1 billion gallons. This industry recycled 14.5 billion gallons per day of water in 1975, with a 2.1 recycle rate. Total recycling is projected to increase to 141.4 billion gallons per day with an increase in the recycle rate to 28 by the year 2000. (Culp, et. al., 1979)

Although closed-cycle water systems (zero-discharge) may be unattractive from an economic perspective, requirements for additional treatment will increase the worth of waters now discarded. (Zero discharge refers to a goal for water-use systems in which all wastes are resources which can be used.) Professionals in the industrial pollution control field recognize that the ultimate goal should be the elimination of materials that affect water qualilty to the maximum possible extent, while giving consideration to the intermedia transfer of pollutants. Reduction of waste volumes by good housekeeping, conservation, and reuse is recommended as the first step in pollution control. The practice of water reuse can be divided into countercurrent use and recycle. Countercurrent use is the practice of using a given water stream for two or more processes or operations before final treatment or disposal. Treatment may or may not occur between each process or operation. Recycling is the practice of recirculating the water within a unit process or group of processes. A combination of these practices may be required for an optimum water reuse scheme. For purposes of definition, reuse is the utilization of water that has been used previously for another purpose; recycle is the reuse of the same water one or more times for the same purpose.[1]

LITERATURE REVIEW

An earlier EPA study examined the extent of water reuse and recycling for the organic chemicals industry and 38 other industrial categories.[2] As a result of an extensive literature search and evaluation, a significant number of reuse and recycle case histories were identified for several industries. Most of the cases involved the removal of inorganic contaminants from wastewaters before their reuse or recycle. Only a few case histories involved the removal of organic contaminants and these dealt primarily with the phenolic derivatives and acetates.

There are several industrial categories where reuse/recycle is an economically viable alternative to conventional wastewater treatment and discharge: plating, pulp and paper and some segments of the mining, food, photoprocessing and inorganic chemical industries. For other industries, there are often insufficient incentives present to promote additional reuse/recycle practices. This is particularly true of the organic chemicals industry. The chief barriers to increased implementation of reuse/recycle include product contamination concerns, treatment technology limitations, cost factors and institutional factors. These will be discussed in another paper at this symposium.

At about the same time as the EPA literature review, the Department of the Interior, Office of Water Research and Technology, completed a comprehensive study of treatment processes and systems which could be utilized to reclaim wastewaters for reuse.[3] Water quality criteria were developed for specific uses and the necessary treatment levels were established. This report stated that reuse of wastewaters by the organic chemical industry appears to be economical but water availability has a significant effect on the price paid for it. Further, it noted that the water quality requirements for this industry vary widely, depending upon the product, and that the prime consideration for reuse is that the water does not interfere with the chemical reactions. In other words, the economic feasibility of using reclaimed wastewaters is site- and process-specific. (If it costs less to reuse wastewater than to buy fresh water, an industry's wastewater will become one of its sources).

After consideration of these earlier studies, the present effort was initiated in 1980 to attempt to identify potential reuse/recycle options for the organic chemical industry.

DISCUSSION

The greatest potential for increased water reuse is expected to be on non-process streams such as cooling water, etc. Major industries such as chemical, pulp and paper, textiles, food, and metals employ a wide range of pollution reducing and water conserving practices including:

- Installation of water saving equipment
- Redesign of manufacturing processes
- Cascaded and countercurrent use of water
- Addition of polishing steps to wastewater treatment facilities with subsequent reuse of treated water
- Stream separation
- Installation of both off-the-shelf and innovative, advanced treatment processes to recover raw materials
- Additional product and byproduct recovery

Using these methods individually or in combination, many plants have achieved reductions of 50 percent and more in water consumption and wastewater discharge.

Because of the diversity of products and processes of the organic chemicals industry, this study concentrated on some of those compounds which are produced in large volume. Basically, specific processes were sought which use large quantities of water and where conditions exist that would promote acceptance and utilization of the concept of reuse/recycle, i.e., effluent guidelines. Subsequent to this, research might be undertaken to overcome the major barriers limiting or precluding adoption of reuse/ recycle technologies by the organic chemicals industry. Some of the organic compounds selected for study are given in Table 1.

The following discussion of acetaldehyde is presented to illustrate the approach used during this study.

Currently, most of the domestic production of acetaldehyde is made by the oxidation of ethylene (Wacker Process). The general diagram for the single-stage process is shown in Figure 1. The process sequence following reaction is 1) remove entrained catalyst from the reactor effluent, 2) condense the reactor effluent, 3) scrub reactor gases with water and recycle, and 4) separate byproducts and water by distillation.

A literature search provided the water balance for the single-stage process (Table 2). A large amount of water is used in the process. A recycle ratio of 3 to 1 is indicated. The potential for additional recycle is low since the single-stage process already makes extensive use of water recycle. However, additional reductions in water use may be possible. One such reduction would require replacement of the live steam to the light ends and the final distillation columns with indirect heat exchangers (reboilers).

The wastewater typically contains acetaldehyde, chloracetic acid, acetic acid and chlorinated acetaldehydes. Catalyst metals (palladium and copper) carried over from the reactor, hydrochloric acid, sulfates and oils are also present. A survey of three acetaldehyde plants (U.S. EPA, 1980) found that one plant used biological treatment and two used deep well disposal. There was no indication that reuse of treated effluents was being practiced. The minimum water quality criteria for reuse in the single-stage process was assumed to be the highest quality water available, or condensate quality. To achieve this, a hypothetical treatment system could require processes including biological, tertiary lime, selective ion exchange and carbon adsorption. The presumed high cost of treatment to upgrade the effluent to condensate quality significantly reduces the potential for reuse.

A two-stage process diagram is given in Figure 2. The water balance for the two-stage process (Table 3) is considerably different than that for the single-stage process. The quantity of wastewater from the two-stage process is smaller (92 gal/1000 lbs). The quality of this wastewater is different than that of the single-stage process: acetaldehyde and acetic acid concentrations are about seven times greater.

The two-stage ethylene oxidation process makes extensive use of water recycle. The potential for additional recycle is low. The wastewater will contain the same type of contaminants as those found in the single-stage process. The high cost of treatment to upgrade wastewater to condensate quality for reuse reduces the potential for reuse. Replacing crude column and acetaldehyde column steam with reboilers would reduce water (steam) usage. The feasibility of this was not determined.

SUMMARY

This study was not completed. Although the preliminary results identified several processes that could be reusing and recycling a larger quantity of process waters, insufficient incentives exist at this time that would promote further reuse/recycle.

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3. Water Reuse and Recycling - Volume 2, Evaluation of Treatment Technology

TABLE 1. Reuse/Recycle Study Compounds

Compound	Annual Capacity (MM Pounds)(1)	Wastewater Flow(2)	Reuse or Recycle Potential
Acetaldehyde	1455	Mod. (one-step)	low
Acetone	3151[3]	low	good (IPA)
Chloromethanes(4)	3503	low	low
Maleic Anhydride	441	mod.	good
Phenol	3563	low-mod.	low (cumene)
Phthalic Anhydride	1391	low	good
Toluene Diisocyanate	750	mod.-high	good-low
Vinyl Chloride	8245	mod.	low

(1) SRI, 1980

(2) high (>10,000 ℓ/1000 kg); mod. (1000-10,000 ℓ/1000 kg); low (<1000 ℓ/1000kg)

(3) 990 MM lbs by IPA process

(4) methyl chloride, methylene chloride, chloroform and carbon tetrachloride.

Table 2. Water Balance for Single-Stage Ethylene Oxidation (SRI, 1976)

	Quantity	
	ℓ/1000 kg Product	gal/1000 lb Product
Influent		
Catalyst Regeneration	95	11
Steam Condensate	2130	256
Light End Column Steam	480	58
Finishing Column Steam	1202	144
HCl Addition	10	1
Steam to O_2 Feed	1170	141
	5087	611
Effluent		
Waste water	5087	611
Recycle		
Scrubber Feed	8200	984
Light Ends Column Reflux	2140	257
Total Recycle Water	10,340	1241

Table 3. Water Balance for Two-Stage Ethylene Oxidation (SRI, 1976)

	Quantity ℓ/1000 kg product	 gal/1000 lb product
Influent		
HCl Make Up	47	6
Crude Column Steam	263	32
Acetaldehyde Column Steam	453	54
	763	92
Effluent		
Acetaldehyde Column Bottoms	631	76
Excess Crude Column Bottoms	125	15
Scrubber Vent	7	1
	763	92
Recycle		
Flash Tower Water	2641	317
Off-Gas Scrubber	2691	323
Off-Air Scrubber	10,828	1300
Total Recycle	16,160	1940

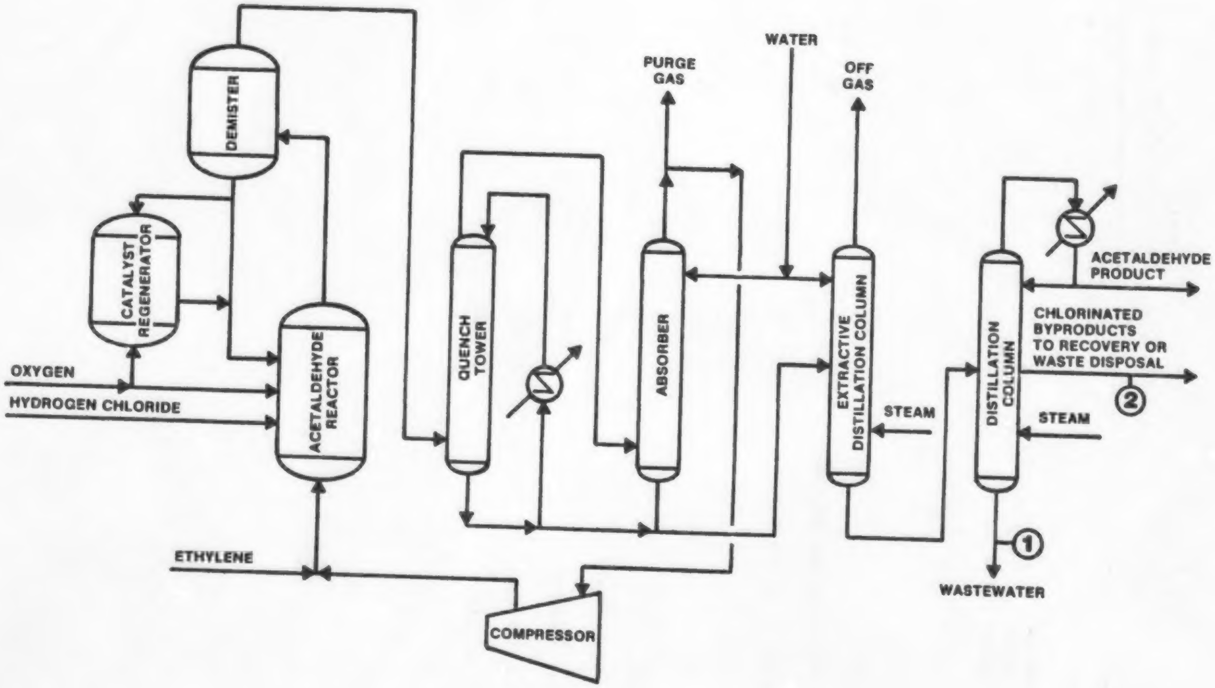
DEMISTER
CATALYST REGENERATOR
OXYGEN
HYDROGEN CHLORIDE
ACETALDEHYDE REACTOR
ETHYLENE
COMPRESSOR
QUENCH TOWER
ABSORBER
PURGE GAS
WATER
OFF GAS
EXTRACTIVE DISTILLATION COLUMN
STEAM
DISTILLATION COLUMN
STEAM
ACETALDEHYDE PRODUCT
CHLORINATED BYPRODUCTS TO RECOVERY OR WASTE DISPOSAL
②
①
WASTEWATER

Figure 1   Acetaldehyde by Oxidation of Ethylene (Single-Stage Process)

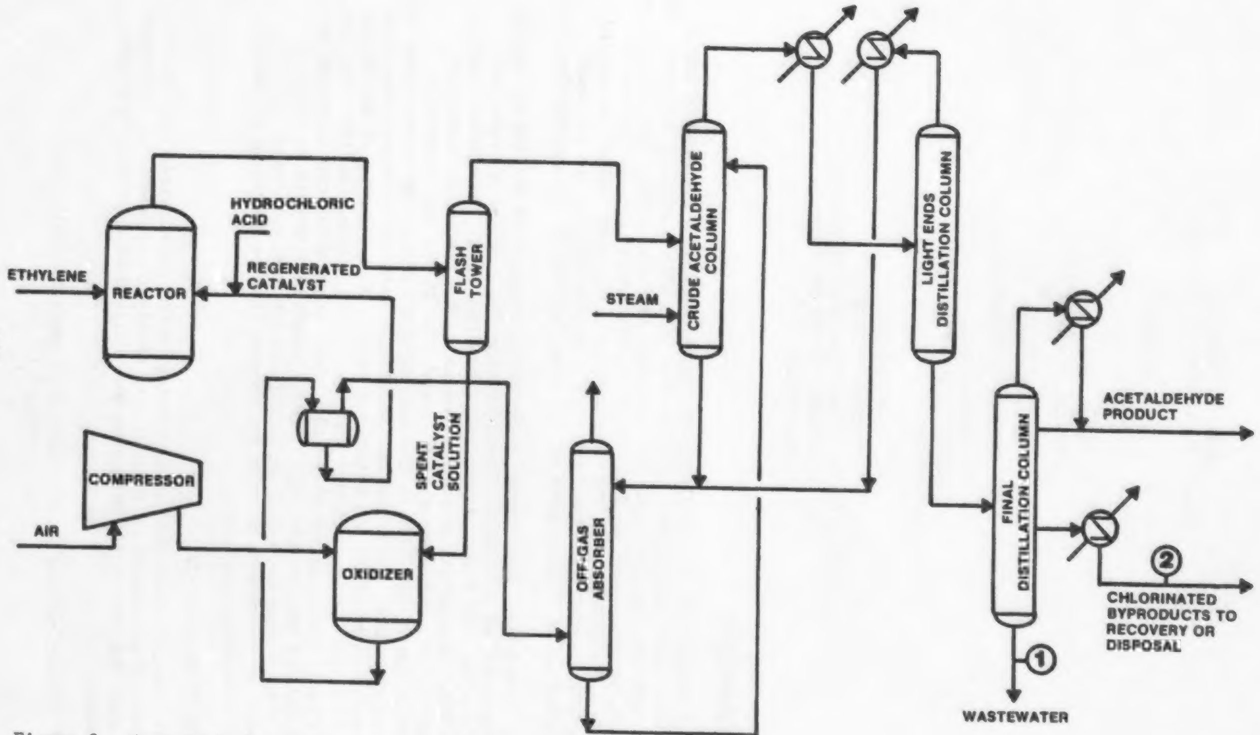
ETHYLENE
REACTOR
HYDROCHLORIC ACID
REGENERATED CATALYST
FLASH TOWER
SPENT CATALYST SOLUTION
COMPRESSOR
AIR
OXIDIZER
STEAM
CRUDE ACETALDEHYDE COLUMN
OFF-GAS ABSORBER
LIGHT ENDS DISTILLATION COLUMN
FINAL DISTILLATION COLUMN
ACETALDEHYDE PRODUCT
②
CHLORINATED BYPRODUCTS TO RECOVERY OR DISPOSAL
①
WASTEWATER

Figure 2 Acetaldehyde by Oxidation of Ethylene (Two-Stage Process)

PB82-223520

WATER RECYCLE AND REUSE POTENTIAL IN THE INORGANIC CHEMICALS INDUSTRY

Edwin F. Rissmann
Senior Environmental Chemist

J. P. LeBoff
Economist

P. A. Hillis
Chemical Engineer

A. M. Twedell*
Environmental Scientist

Versar Inc.
6621 Electronic Drive
Springfield, Virginia 22151

Jay Garvin
Project Officer
Office of Water Research and Technology
U.S. Department of the Interior
Washington, D.C.

INTRODUCTION

The purpose of this study was to assess the current status of wastewater reuse and recycle (r/r) in the inorganic chemicals industry, and to project recycle/reuse for the years 1985 and 2000. "Recycling," as used in this paper is defined as the successive use of process or cooling wastewater in the same process. The term "reuse" is applied to wastewaters that are discharged from one process and are used either in another process at the same facility or by another facility.

In this study, the inorganic chemicals industry is defined to include six Standard Industrial Classification (SIC) codes: Alkalies and Chlorine (SIC 2812); Industrial Gases (SIC 2813); Inorganic Pigments (2816); Industrial Inorganic Chemicals, Not Elsewhere Classified (SIC 2819); Nitrogenous Fertilizers (SIC 2873); and Phosphatic Fertilizers (SIC 2874). The manufacturers classified under these SIC codes produce, in industrial quantities, over 600 chemicals and chemical products from inorganic compounds. This industry is one of the major water using industries in the United States. In 1980, the inorganic chemicals industry had a total gross water use in excess of 3 billion gallons per day. Future water requirements in this industry were estimated on a national and regional basis, as well as the amount of this requirement that is likely to be satisfied by wastewater recycle.

STUDY METHODOLOGY

In the inorganic chemicals industry, water requirements per ton of product and degree of recycle vary widely among products. Consequently, water use and recyle estimates were derived on a product-by-product basis.

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* Present address: Association of American Railroads
Washington, D.C.

Initially, estimates of gross water use were derived for each product by multiplying annual production figures by water use per ton of product. Production figures for most chemicals were obtained from the Current Industrial Reports: Inorganic Chemicals - 1979, issued by the Bureau of the Census. Water use data estimates were obtained from the open literature, industry supplied data, and a recently completed "Multimedia Assessment of the Inorganic Chemicals Industry."(1) This water use information was subsequently revised based on information received from industrial sources. For chemicals where ranges of water use per ton of product were found, the highest values were assumed so that no significant water using segment would be excluded from the study.

This exercise was applied to the 600 inorganic chemical products produced in industrial quantities. Based on these calculations, it was determined that 98 percent of the total gross water use was concentrated in 40 product areas, each of which had a gross water use requirement in excess of 1 million gallons per day. This figure was then used as a cut-off value in order to make the study more manageable and allow it to be focused on the major water using segments of the industry. The 40 water using segments selected are listed in Table I.

After further investigation, this list was reduced to 30 product segments. The 10 excluded segments were:

- Calcium carbonate--Wet precipitation process is being phased out of existence.
- Calcium hydroxide--Increased use of dry air pollution control equipment has considerably reduced water requirements. The remainder of the water used is consumed in the product.
- Magnesium and magnesium hydroxides--Water used is either brine or seawater. After recovery of product materials, these are returned to their sources.
- Bromine, sodium sulfate, and calcium chloride--Derived from natural brines that are normally returned to their sources of fully evaporated. Some sodium sulfate is also recovered as a by-product of several organic chemical manufacturing operations.
- Frasch sulfur--The steam injected for solution mining of the sulfur from salt formations is converted in to highly corrosive brine wastewater, which cannot be recycled without extensive treatment. Additionally, the opportunity for reuse does not exist because the locations where sulfur is produced are isolated areas in Texas and Louisiana. At sites where sulfur occurs in anhydrite deposits, the water is currently totally reused. At offshore sites, it is discharged to the sea.
- Sodium carbonate (produced by the Solvay Process)--This is currently used only at one location. Since 1969, six of seven Solvay plants have been closed, largely because of energy related cost problems. The last plant is expected to terminate operations within the next four years because of increased energy costs.

- Titanium tetrachloride—Revised water use data received from the industry indicated a gross water use of only about 500,000 GPD nationwide.

The data used to compile these water use estimates did not include auxiliary non-chemical water uses sometimes present at production sites. Water for sanitary purposes and onsite electric power generation was not included. Total gross water use was estimated to be over 3 billion gallons per day for the 30 major water products using segments. This was estimated to be about 80 percent of the total gross water used for chemical production purposes in the industry. These estimated water requirements contrast favorably with the 5.9 billion gallon gross water use for chemical and non-chemical purposes for this industry estimated by the Department of Commerce study.(2)

Once estimates were obtained for current gross water used, an examination was made of the nature of the water use on a product-by-product basis. The amounts of water currently recycled were estimated based on published data and information solicited from the industry.

After the current status of gross water reuse and recycle was defined, projections were made for 1985 and 2000. In developing these projections, product segments were identified where recycle is currently technologically practical. Situations were also identified where increased use of recycle is expected to occur. Such cases were those where increased recycle would result from environmental regulations or changes in process technology likely to be adopted industry-wide in the next few years. In developing the projections, data on expected growth rates of the different product segments were based on Predicast Composite Forecasts of future production in 1985 and 1995 for specific non-durable manufacturing sections. These forecasts are published as Predicasts Forecasts(3) and are summarized for the products studied in Table 2. Overall water use is summarized in Table 3.

RESULTS

Based on the results of industrial information supplied to this effort and on data obtained from the literature, an assessment of the current status of water recycle was made. The results, summarized in Table 4, show on a product-by-product basis the status of water recycle in each of the 30 product segments studied. As can be seen, the degree of recycle varies radically from one product segment to another. In nine product segments, all water used is either recycled or consumed in the production process. These segments are aluminum sulfate, ammonium sulfate, calcium phosphate, calcium sulfate, hydrochloric acid, wet or dry process phosphoric acid, plating chemicals, and sodium chloride. Also, most ammonium nitrate plants currently have no discharge.

Of the remaining 20 segments, several generate highly saline wastewater which is not suitable for either recycle or reuse. Some of these segments, however, do recycle some of their non-contact cooling water. This recycle is practical only at some locations and is generally governed by overall plant water handling practices. The seven product categories where recycle of process wastewater was determined to be impractical are:

calcium oxide
chrome pigments
hydrogen peroxide
potassium chloride
sulfamic acid
titanium dioxide
sodium dichromate

The highly saline conditions of the wastewater effectively prevent economical recycle in these cases. Only for calcium oxide, where the water is used for air emissions control, can water use be eliminated by installation of a substitute system (i.e., dry air emissions control systems). No such substitute is possible for the other cases.

Three segments (nitric acid, sulfuric acid, and zinc oxide) currently discharge spent cooling water and could theoretically reuse this water. However, in these segments, there is no incentive for modifying existing cooling water plant circuits to allow for recycle.

The remaining ten segments of the industry are discussed below.

ALUMINA

In the production of alumina, water is used for the following purposes:

- For cooling.
- For transport of solid "red mud" wastes to disposal areas.
- For dilution of intermediate sodium aluminate liquors prior to recovery of an aluminum hydroxide intermediate.

Process water used to transport solid wastes to disposal areas is currently recycled at all 10 U.S. alumina plants. The only water discharged from the waste transport water cycle is excess rainfall introduced into the disposal lagoons. This excess water is chemically treated prior to discharge.

Direct process dilution water leaves the process during reconstitution of the recovered dilute caustic soda raw material by solution evaporation. However, at most plants, this water is recovered in barometric condenser systems and leaves the plant with the spent cooling water. Presently, 6 of the 10 facilities use barometric condensers, and 2 plants employ tube and shell type condensers. Plants using barometric systems employ once-through cooling water to avoid buildup of salts and caustic in the cooling water circuit. While this problem has been solved at 2 plants by the use of non-contact tube and shell condensers, there is currently no incentive for the remaining plants to install such systems to permit recovery and recycle of the condensates and separate recycle of the cooling water. All U.S. plants are located either on the Gulf Coast or in Arkansas. In all cases, adequate water supplies are locally available. Also, several of the plants are located in multi-product complexes with integrated water handling systems. Additional products produced at these plants include chlorine and caustic soda, hydrofluoric acid, and various fluorocarbon chemicals. All of the current alumina plants were built prior to 1960.

AMMONIA

Water is used in ammonia production for two purposes:

- For non-contact cooling and heating purposes.
- As a raw material (steam) for the process.

Most ammonia plants currently recycle most of their cooling water and non-contact heating steam, discharging only about five percent of these waters as blowdown. Overall, about 75 percent of these waters are currently recycled. Two plants are currently using treated municipal wastewater as makeup water for these purposes.

Process wastewater consists of condensate that exits the process at about 80°C; it results from the use of excess steam in the initial portion of the process. Most plants currently steam strip this wastewater to remove dissolved ammonia and then discharge it. However, most of the plants built since 1976 reinject this water into the plant boiler system and then reuse the steam for process purposes. This modification was adopted as an energy conservation feature in new plant design.

Most ammonia plants are operated by fertilizer companies which do not have the captive engineering and design capability needed to modify older plants. Industry practice has been to run existing facilities for their full lifetimes and to install process improvements only on new facilities while they are under construction.

Thus, while technology now exists for increasing recycle in this product segment, such technology will increase in use only as old plants are closed and new ones are constructed. The average lifetime of an ammonia plant is about 30 years.

BORAX

Water is used in borax production from ore operations for the following purposes:

- Non-contact cooling.
- As a solvent medium from which the product is recovered by crystallization.
- For transport of wastes to disposal areas.

At present, only one plant produces borax from ores. At that site, most cooling water is recycled, except for a small amount of blowdown. Some of the waste transport water and most of the process water is also currently recycled. Conservation of additional water is theoretically possible, but presently not cost effective because of the high plant modification expenses involved. This plant presently recycles about 80 percent of its water.

CHLOR-ALKALI

The chlor-alkali segment of the industry has perhaps the most complex water use pattern. About 95 percent of the total production utilizes mercury and diaphragm cell electrolytic processes.

In mercury cell plants, the bulk of the process water is currently recycled. The only process wastewater discharged is scrubber wastewater and small amounts of brine purged from the circuits to avoid buildup of impurities. Cooling water recycle is on a plant-specific basis. Some facilities recycle most of their cooling water, while others employ once-through cooling circuits. The type of cooling water handling system employed depends on plant location, types of product, and the nature of other products manufactured at the same sites. While such additional cooling water could be recycled, there is presently little incentive for modifying plant cooling water circuits to allow for such recycle. No mercury cell plants are located in water-deficient areas.

Water is used in the diaphragm cell process for the following applications:

- As an electrolysis solvent media.
- For control of process air emissions.
- For recrystallization and purification of recovered uncreacted salt.
- For cooling purposes.

Generally, raw brine (containing about 25 percent sodium chloride) is used as the raw material. This liquor is converted into a sodium hydroxide-sodium chloride solution during electrolysis. This solution is then evaporated in steps, first to recover the unreacted sodium chloride and then to recover solid caustic soda. The evaporators used are normally equipped with barometric condensers so that condensates, containing traces of salt and caustic soda depart the process with the spent cooling water.

Wastewaters from air emissions control operations are generally discharged after treatment. Wastewater from salt recrystallization is also discharged. Because of the use of barometric condensers, the spent cooling water is normally not recycled.

Although technologies do exist to recycle all of the above wastewater streams, they are normally not used. There are no incentives, for example, to replace the barometric condenser systems with tube and shell condensers to achieve cooling water and condensate reuse because almost all of the diaphragm cell capacity is located in water-rich areas. The abundance of water does not encourage costly plant modifications.

HYDROFLUORIC ACID

Another segment where increased recycle is possible is the hydrofluoric acid production segment. Water is used in this segment for the following purposes:

- Non-contact cooling.
- Air emissions control.
- Transport of solid wastes to disposal areas.

The recycle of cooling water differs from plant to plant. Several plants are located in integrated complexes using once-through cooling water systems. These plants have no incentive to modify existing cooling water use practices.

All process wastewater is generally combined prior to treatment and discharge. Presently, two plants recycle their treated process wastewater. However, recent effluent guidelines regulations have mandated that at least 43 percent of the process wastewater be recycled. These proposed regulations are expected to take effect in 1984 and to increase the amount of recycle practiced by this product segment.

SODA ASH

The natural soda ash segment is another area where increased recycle is likely to occur. Four plants, all located in Wyoming, presently process mined trona ore to recover soda ash. At these locations, water is used for the following purposes:

- Non-contact cooling.
- Ore processing and product recovery operations.
- Transport of solid wastes to disposal area.

All plants currently recycle most of their cooling water, discharging only a small amount of blowdown to evaporation ponds. At least two facilities recycle most of the process water and a portion of the waste transport water. The status of process water recycle at the other two plants is unknown. All plants dispose of wastewater at onsite evaporation lagoons.

All natural soda ash plants are located within 10 miles of the Green River, a tributary of the Colorado River. With increased water demand in the area for future petroleum and oil shale operations, it is anticipated that this industry segment will have to increase its recycle of wastewater.

PHOSPHORUS

The phosphorus production segment of the industry is located in three areas: the Tennessee Valley, Florida, and the Idaho-Montana phosphate belt. Water is used in phosphorus production for the following purposes:

- As a condensation medium for collection of the phosphorus.
- Non-contact cooling.
- For air emissions control.

Water used as a condensation medium is generally treated to oxidize the phosphorus and is then recycled at all eight phosphorus plants. Non-contact cooling water and scrubber waters are likewise recycled at six of the eight facilities. At two plants, however, non-contact cooling water is used on a once-through basis and scrubber water is discharged after treatment to remove fluorides, phosphates, and suspended materials. The two facilities currently discharging these wastewaters are both located on major rivers and have no incentive to modify existing plant water handling systems.

SODIUM CHLORATE

Water is used in sodium chlorate manufacture for the following purposes:

- As an electrolysis medium.
- For cooling purposes.
- For airborne emissions control.

The electrolysis liquor is lost by evaporation at most plants. A few facilities manufacture only a solution grade product in these cases, the process water is incorporated into the production process.

Scrubber water is used for process makeup water at all plants. Cooling water is recycled at some facilities and discharged at others. The choice here depends on the type of product and the type of condensers used with the evaporators. Plants producing only a solution grade product and those using tube and shell condensers are able to recycle their cooling water. Plants using barometric condensers, however, produce spent cooling water contaminated with evaporative carry over and are forced to discharge it after treatment. Presently, there is little incentive to modify existing cooling water circuits or to replace condensers.

SODIUM PHOSPHATE

Water is used in sodium phosphate production chiefly for airborne emissions control purposes. At plants producing a lower grade product, the spent scrubber water is periodically purged to the process circuit to recover added material. At plants making higher grade product, however, this option is not practiced because objectionable materials could be introduced into the product. No sodium phosphate plants are located in water deficient areas.

SODIUM SILICATE

Water is used in sodium silicate production for three purposes:

- For non-contact cooling.
- For preparation for solution grade product.
- For air emission control.

The sodium silicate segment of the industry is quite diverse relative to water use. This diversity includes:

- Use of air cooled and water cooled furnaces.
- Production of both solid products and solution products.
- Use of both wet and dry air pollution control systems.

Presently there is not incentive for converting to dry processes. About 60 percent of the plants use dry pollution control systems, and about 20 percent use air cooled furnaces. Most sodium silicate plants discharge both the spent cooling water and scrubber water. However, both water uses could be eliminated by the use of air cooled furnaces and dry particulate collection systems.

The overall status of current water use and potential recycle is summarized in Table 4 for all of the 30 product segments examined.

Once data was developed on current water use and handling practices and on recycle potential for all of the 30 segments involved, an assessment was made of the degree to which recycle is likely to be practiced in the future for this industry. Factors considered were the impacts of technology advances, economics, and regulatory impact. This analysis identified three product areas where increased recycle is likely. These are:

- Ammonia, where the use of new process technology should lead to an increase in process water recycle.
- Hydrofluoric acid, where increased recycle of process water has been mandated by environmental regulations.
- Natural soda ash, where local water availability problems may force additional recycle.

This information was then used to project recycle activity for the years 1985 and 2000. Our estimates for these two years are given in Tables 5 and 6. The specific percent recycle assumptions used for deriving the recycle estimates of Tables 5 and 6 are summarized in Table 4. These estimates were derived by multiplying gross water use estimates by the recycle percentages (i.e., percent of gross water use recycled). The recycle percentages were based on an examination of current industry practices, water quality requirements, environmental regulations, water requirements relative to regional water supplies, economic incentives, and new existing technologies. The assumptions used in deriving the projected recycle percentages may be summarized as follows:

- Those industry segments already practicing full recycle will continue to do so.
- Barring major technological breakthroughs, those segments where recycle is currently impractical because of process water quality requirements will not increase recycling in the future.
- Those industry segments located largely in multi-product complexes with integrated water-handling systems will continue current practices except in areas where changes are mandated by regulations.

Another implicit assumption made in deriving these estimates was that the distribution of plant locations by water region was not expected to change radically in the next 20 years. This implies that there will be no significant shift of the industry towards areas of the country which are water deficient. The present industry distribution on a water region basis is shown for the 30 product areas studied in Table 7.

Increased recycle will occur only in those segments where it is:

- Mandated by regulations.
- The result of new energy efficient technology.
- Needed because of limited water supplies.

DISCUSSION OF RESULTS

The analysis shows that while there is a considerable potential for wastewater recycle in this industry, increased use of recycle technology is likely to be limited to a few product segments. In those areas, increased recycling will result from environmental regulations, advances in process technology, and a number of dependent factors.

Most of the industry currently lacks the incentive needed for adopting recycle technology. Large amounts of spent non-contact cooling water that are presently discharged from several process segments could be recycled using present technology. However, recycling of water would involve installation of cooling ponds or cooling towers. About two-thirds of the gross water use in this industry occurs in water excess areas in the eastern half of the United States. Only about 15 percent of the gross water use occurs in arid or water deficient areas. As a result, there is little incentive for this industry, overall, to modify existing water handling practices and to increase the recycling or re-use of spent cooling water.

One exception to the above situation may exist for plants located in water deficient regions. At present, a significant percentage of the gross water use in the California, Lower Colorado, Great Basin and Rio Grande water regions is for non-contact cooling water in sulfuric acid production. Many of these sites are located at or adjacent to zinc or copper smelters where some opportunity may exist for the reuse of spent cooling water.

For process water, the situation is far more complex. Some process waters are presently entirely recycled. These consist largely of waste transport water from the production of alumina, calcium sulfate, and wet process phosphoric acid. Other process wastewater streams, however, are contaminated with various dissolved solids and are thus unsuitable for recycle without application of some type of desalination technology. Although methods, such as distillation and reverse osmosis, do exist for removal of dissolved solids from wastewater, these technologies are presently too expensive to enjoy large scale use. Clearly, a need exists to develop lower cost methods for removal of dissolved solids from wastewater.

Another route to reducing wastewater in the chemical industry lies in process modifications which reduce overall process water volume requirements. Such modifications include the use of dry capture systems for particulate emissions control and the use of non-aqueous solvents for control of some gaseous emissions. These modifications are currently being explored to some degree by the lime, sodium silicate, and the chlor-alkali segments of the industry.

The foregoing analysis is based on two assumptions:

- That industrial practices will remain unchanged except in those cases where either regulations or new process developments make it more advantageous to increase reuse/recycle of water.
- That the location distribution of future new plants will essentially parallel that of existing facilities.

The first assumption presumes that industry will use classical rate of return criteria in deciding on plant modifications in future years. Areas where increased recycling is likely to be cost effective are in the ammonia, hydrofluoric acid, and natural soda ash segments of the industry, as discussed earlier. The second assumption reflects the fact that plant locations have historically been selected on the basis of raw material availabilities and sources, local energy costs, and distance from anticipated markets.

CONCLUSIONS

Our assessment of the potential for water recycle in the inorganic chemicals industry has led to the conclusion that, while there is a potential for a considerable amount of increased recycle in this industry, particularly of cooling water, this potential is unlikely to be realized because of a number of location dependent and economic factors. The bulk of this industry is located in water excess areas (i.e., the eastern U.S. and the Gulf Coast) and has had no incentive to modify existing water use practices beyond that required to meet environmental regulations. There are, of course, a few exceptions to the overall findings, but these exceptions occur in product segment areas which are either currently being influenced by new process technology or are located largely in water deficient areas where increased demand for limited water supplies in future years is likely to make increased recycling more attractive.

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TABLE 1
MAJOR WATER USING PRODUCT SEGMENTS OF THE INORGANIC CHEMICALS INDUSTRY

alumina
aluminum sulfate (alum)
ammonia
ammonium nitrate
ammonium sulfate
bromine
calcium carbonate (precipitated)
calcium chloride
calcium phosphate
calcium sulfate
chlorine/caustic
chrome pigments
hydrochloric acid
hydrofluoric acid
hydrogen peroxide
lime (calcium oxide)
magnesia
magnesium hydroxide
nitric acid
wet and dry process phosphoric acid
phosphorus
plating chemicals
potassium chloride
slaked lime (calcium hydroxide)
sodium borate dicalydrate (boxax)
sodium carbonate (natural and Solvay)
sodium chlorate
sodium chloride
sodium dichromate
sodium phosphate
sodium silicate
sodium sulfate
sulfanic acid
sulfuric acid
sulfur (Frasch)
titanium dioxide
titanium titrachloride
zinc oxide

TABLE 2
PRODUCTION ESTIMATES AND GROWTH RATE ASSUMPTIONS

Product	1980 Production (tons/year)	Average Annual Growth Rates (Percent)	
		1980-1985	1985-2000
alumina	6.4×10^6	4.8	3.3
aluminium sulfate	1.3×10^6	4.8	3.3
ammonia	18.5×10^6	3.1	2.3
ammonium nitrate	7.5×10^6	3.1	2.3
ammonium sulfate	2.4×10^6	3.1	2.3
calcium phosphate	8.3×10^5	4.8	3.3
calcium sulfate	9.1×10^6	4.8	3.3
chlorine/caustic	12.2×10^6	4.8	3.3
chrome pigments	7.0×10^4	3.7	3.1
hydrochloric acid	3.1×10^6	4.8	3.3
hydrofluoric acid	1.8×10^5	4.8	3.3
hydrogen peroxide	1.1×10^5	4.8	3.3
lime	16.8×10^6	4.8	3.3
nitric acid	8.5×10^6	3.1	2.3
phosphoric acid (dry)	7.6×10^5	3.1	2.3
phosphoric acid (wet)	10.3×10^6	3.1	2.3
phosphorus	4.6×10^5	4.8	2.3
plating chemicals	1.0×10^5	4.8	3.3
potassium chloride	2.4×10^6	-3.2	-1.1
sodium borate	7.9×10^5	4.8	3.3
sodium carbonate	8.25×10^6	4.8	3.3
sodium chlorate	2.7×10^5	4.8	3.3
sodium chloride	2.4×10^6	4.8	3.3
sodium dichromate	1.6×10^5	4.8	3.3
sodium phospahte	7.6×10^5	4.8	3.3
sodium silicate	7.7×10^5	4.8	3.3
sulfamic acid	5.0×10^4	4.8	3.3
sulfuric acid	4.3×10^7	4.8	3.3
titanium dioxide	7.4×10^5	3.7	3.1
zinc oxide	1.7×10^5	3.7	3.1

TABLE 3

ESTIMATES OF WATER USE IN 1980 FOR THE 30 MAJOR WATER-USING SEGMENTS OF THE INORGANIC CHEMICALS INDUSTRY

(gallons per day)

Product Segment	Gross Water Use	Water Recycle *	Consumption *	Withdrawal	Process Discharge
Alumina	7.1×10^8	2.5×10^8	0	4.6×10^8	4.6×10^8
Aluminum Sulfate	1.4×10^6	3.5×10^5	1.1×10^6	1.1×10^6	0
Ammonia	3.4×10^8	2.3×10^8	2.0×10^7	1.1×10^8	9.0×10^7
Ammonium Nitrate	1.1×10^7	8.0×10^6	2.8×10^6	3.0×10^6	2.0×10^5 †
Ammonium Sulfate	3.3×10^6	2.6×10^6	7.0×10^5	7.0×10^5	0
Calcium Oxide	6.7×10^6	0	0	6.7×10^6	6.7×10^6
Calcium Phosphate	5.4×10^6	3.2×10^6	2.2×10^6	2.2×10^6	0
Calcium Sulfate	6.1×10^7	5.65×10^7	4.6×10^6	4.6×10^6	0
Chlorine/Caustic	4.8×10^8	1.0×10^8	1.3×10^7	3.8×10^8	3.7×10^8
Chrome Pigments	5.5×10^6	0	0	5.5×10^6	5.5×10^6
Hydrochloric Acid	8.9×10^6	0	8.0×10^6	8.0×10^6	0
Hydrofluoric Acid	8.9×10^7	1.4×10^7	6.1×10^5	7.5×10^7	7.4×10^7
Hydrogen Peroxide	7.3×10^6	1.8×10^6	0	5.5×10^6	5.5×10^6
Nitric Acid	2.8×10^7	0	1.5×10^6	2.8×10^7	2.7×10^7
Phosphoric Acid (dry)	6.9×10^6	0	6.9×10^6	6.9×10^6	0
Phosphoric Acid (wet)	1.9×10^8	1.7×10^8	2.0×10^7	2.0×10^7	0
Phosphorus	4.6×10^6	2.6×10^6	0	2.1×10^6	2.1×10^6
Plating Chemicals	1.0×10^6	0	1.0×10^6	1.0×10^6	0 ††
Potassium Chloride	4.6×10^6	0	0	4.6×10^6	4.6×10^6
Sodium Carbonate	1.7×10^7	1.0×10^7	0	7.0×10^6	7.0×10^6
Sodium Chlorate	1.5×10^6	8.0×10^5	8.3×10^4	7.0×10^5	6.2×10^5
Sodium Chloride	2.9×10^6	0	2.9×10^6	2.9×10^6	0
Sodium Phosphate	4.0×10^7	2.4×10^7	0	1.6×10^7	1.6×10^7
Sodium Silicate	1.0×10^6	0	4.4×10^5	1.0×10^6	5.6×10^5
Sulfamic Acid	5.0×10^6	0	0	5.0×10^6	5.0×10^6
Sulfuric Acid	6.6×10^8	6.0×10^6	5.2×10^6	6.5×10^8	64.8×10^7
Titanium Dioxide	2.4×10^8	2.4×10^7	0	2.2×10^8	2.2×10^8
Zinc Oxide	5.0×10^6	0	0	5.0×10^6	5.0×10^6
Other**	4.9×10^6	2.8×10^6	0	2.1×10^6	2.1×10^6
Total	3.0×10^9	9.5×10^8	8.8×10^7	2.0×10^9	1.9×10^9

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* "0" indicates less than 2 percent of gross water use.

** Other includes two product segments (sodium borate decahydrate and sodium dichromate) that are produced at fewer than three plants nationwide.

† At a few plants only, water is discharged to a second process for urea production. Most plants have no discharge.

†† There are no effluents from plating chemicals production if pure raw materials are used. One plant does use a small percentage of impure raw materials and produces a small discharge.

TABLE 4. GROSS WATER USE ESTIMATES AND PERCENT RECYCLE ASSUMPTIONS

CHEMICAL	ESTIMATED GROSS WATER USE 1980 (GPD)	PERCENT RECYCLED 1980	PERCENT RECYCLED 1985	PERCENT RECYCLED 2000	COMMENTS
Alumina	5.4×10^{8} (cooling)	18 (cooling)	18 (cooling)	18 (cooling)	Two facilities (comprising 19% of total production capacity) completely recycle cooling water. Rest of plants discharge spent cooling water.
	1.7×10^{9} (process)	80 (process)	80 (process)	80 (process)	Most process water recycled except for evaporative carryover which is combined with spent cooling water prior to discharge.
Aluminum sulfate	1.4×10^{6}	25	25	25	Balance of water lost in sludge.
Ammonia	4.0×10^{7} (process)	12 (process)	22 (process)	62 (process)	Based on assumption that all new plants will use new technology and that a plant's life is 30 years.
	3×10^{8} (cooling)	75 (cooling)	75 (cooling)	75 (cooling)	
Ammonium nitrate	1.1×10^{7}	75	75	75	Balance lost by evaporation.
Ammonium sulfate	3.3×10^{6}	75	75	75	Balance lost by evaporation.
Calcium oxide	6.7×10^{6}	nil	nil	nil	
Calcium phosphate	5.4×10^{6}	100	100	100	
Calcium sulfate	1.0×10^{8}	100	100	100	
Chlorine/caustic	4.8×10^{9}	20	20	20	Most process water in mercury cell plants is recycled; sizable water recycle occurs at only one diaphragm cell plant. Cooling water is generally not recycled at most facilities.
Chrome pigments	5.5×10^{6}	None	None	None	
Hydrochloric acid	8.0×10^{6}	nil	nil	nil	Water used is consumed in product.
Hydrofluoric acid	8.9×10^{7}	15	45	45	Two plants presently recycle 80 percent; 45 percent mandated by 1985 in new BPT regulations.

TABLE 4. GROSS WATER USE ESTIMATES AND PERCENT RECYCLE ASSUMPTIONS (Continued)

CHEMICAL	ESTIMATED GROSS WATER USE 1980 (GPD)	PERCENT RECYCLED 1980	PERCENT RECYCLED 1985	PERCENT RECYCLED 2000	COMMENTS
Hydrogen peroxide	7.3×10^{6}	25	25	25	Some cooling water recycle is practiced.
Nitric acid	2.8×10^{7}	nil	nil	nil	
Phosphoric acid (dry process)	6.9×10^{6}	nil	nil	nil	Water consumed in product.
Phosphoric acid (wet process)	1.9×10^{8}	100	100	100	
Phosphorus	4.5×10^{6}	55	55	55	Seven plants (55 percent of production capacity) recycle 90 percent of the cooling or scrubber water. Two plants (45 percent of production capacity) recycle of the cooling or scrubber water. All plants recycle their phosphorus condensation liquors.
Plating Chemicals	1.0×10^{6}	nil	nil	nil	
Potassium chloride (ore)	4.6×10^{6}	nil	nil	nil	Production from ores is expected to decline due to depletion of reserves.
Sodium borate and boric acid	3.4×10^{6}	90	90	90	Cooling water presently recycled; one plant recycles 50 percent of its process water.
Sodium carbonate (natural)	1.7×10^{7}	60	70	70	
Sodium chlorate	1.5×10^{6}	95	95	95	Most cooling water recycled. Most process water evaporated.
Sodium chloride	2.9×10^{6}	nil	nil	nil	
Sodium dichromate	1.9×10^{6}	nil	nil	nil	

TABLE 4. GROSS WATER USE ESTIMATES AND PERCENT RECYCLE ASSUMPTIONS
(Continued)

CHEMICAL	ESTIMATED GROSS WATER USE 1980 (GPD)	PERCENT RECYCLED 1980	PERCENT RECYCLED 1985	PERCENT RECYCLED 2000	COMMENTS
Sodium phosphate	4.0×10^7	60	60	60	Water use based on highest reported cooling water estimate.
Sodium silicate	1.0×10^6	nil	nil	nil	
Sulfamic acid	5.0×10^6	nil	nil	nil	
Sulfuric acid	6.6×10^8	nil	nil	nil	Two very small plants known to recycle cooling water. This practice is not typical.
Titanium dioxide	2.4×10^8	10	10	10	Cooling water is recycled at two chloride process plants.
Zinc oxide	5.0×10^6	nil	nil	nil	

TABLE 5

ESTIMATES OF WATER USE IN 1985 FOR THE 30 MAJOR WATER-USING SEGMENTS OF THE INORGANIC CHEMICALS INDUSTRY
(gallons per day)

Product Segment	Gross Water Use	Water Recycle*	Consumption*	Withdrawal	Process Discharge
Alumina	8.9×10^8	3.1×10^8	0	5.8×10^8	5.8×10^8
Aluminum Sulfate	1.8×10^6	4.4×10^5	1.4×10^6	1.4×10^6	0
Ammonia	4.0×10^8	2.7×10^8	2.4×10^7	1.3×10^8	1.1×10^8
Ammonium Nitrate	1.3×10^7	1.0×10^7	3.0×10^6	3.0×10^6	0
Ammonium Sulfate	3.9×10^6	2.9×10^6	9.8×10^5	1.0×10^6	2.0×10^4
Calcium Oxide	8.4×10^6	0	0	8.4×10^6	8.4×10^6
Calcium Phosphate	6.8×10^6	4.0×10^6	2.8×10^6	2.8×10^6	0
Calcium Sulfate	7.70×10^7	7.12×10^7	5.8×10^6	5.8×10^6	0
Chlorine/Caustic	6.0×10^8	1.2×10^8	1.6×10^7	4.8×10^8	4.6×10^8
Chrome Pigments	6.6×10^6	0	0	6.6×10^6	6.6×10^6
Hydrochloric Acid	10.1×10^6	0	10.1×10^6	10.1×10^6	0
Hydrofluoric Acid	11.2×10^7	5.0×10^7	7.7×10^5	6.2×10^7	6.1×10^7
Hydrogen Peroxide	9.2×10^6	2.3×10^6	0	6.9×10^6	6.9×10^6
Nitric Acid	3.3×10^7	0	1.7×10^6	3.3×10^7	3.1×10^7
Phosphoric Acid (dry)	8.1×10^6	0	8.1×10^6	8.1×10^6	0
Phosphoric Acid (wet)	2.2×10^8	1.97×10^8	2.3×10^7	2.3×10^7	0
Phosphorus	5.4×10^6	3.0×10^6	0	2.4×10^6	2.4×10^6
Plating Chemicals	1.3×10^6	0	1.3×10^6	1.3×10^6	0
Potassium Chloride	4.0×10^6	0	0	4.0×10^6	4.0×10^6
Sodium Carbonate	2.1×10^7	1.5×10^7	0	6.0×10^6	6.0×10^6
Sodium Chlorate	1.9×10^6	1.0×10^6	1.0×10^5	9.0×10^5	8.0×10^5
Sodium Chloride	3.7×10^6	0	3.7×10^6	3.7×10^6	0
Sodium Phosphate	5.0×10^7	3.0×10^7	0	2.0×10^7	2.0×10^7
Sodium Silicate	1.3×10^6	0	5.5×10^5	1.3×10^6	7.5×10^5
Sulfamic Acid	6.3×10^6	0	0	5.3×10^6	6.3×10^6
Sulfuric Acid	8.3×10^8	8.3×10^6	6.5×10^6	8.2×10^8	8.1×10^8
Titanium Dioxide	2.9×10^8	2.9×10^7	0	2.6×10^8	2.6×10^8
Zinc Oxide	6.0×10^6	0	0	6.0×10^6	6.0×10^6
Other**	6.2×10^6	3.4×10^6	0	2.8×10^6	2.8×10^6
Total	3.7×10^9	1.2×10^9	1.1×10^8	2.5×10^9	2.4×10^9

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* "0" indicates less than 2 percent of gross water use.

** Other includes two product segments (sodium borate decahydrate and sodium dichromate) that are produced at fewer than three plants nationwide.

TABLE 6

ESTIMATES OF WATER USE IN 2000 FOR THE 30 MAJOR WATER-USING SEGMENTS OF THE INORGANIC CHEMICALS INDUSTRY (gallons per day)

Product Segment	Gross Water Use	Water Recycle *	Consumption *	Withdrawal	Process Discharge
Alumina	1.5×10^{9}	5.1×10^{8}	0	9.9×10^{8}	9.9×10^{8}
Aluminum Sulfate	2.9×10^{6}	7.2×10^{5}	2.2×10^{6}	2.2×10^{6}	0
Ammonia	1.2×10^{9}	4.1×10^{8}	3.3×10^{7}	7.9×10^{8}	7.6×10^{8}
Ammonium Nitrate	1.8×10^{7}	1.4×10^{7}	4.0×10^{6}	4.0×10^{6}	0
Ammonium Sulfate	5.5×10^{6}	4.1×10^{6}	1.4×10^{6}	1.4×10^{6}	0
Calcium Oxide	13.7×10^{6}	0	0	13.7×10^{6}	13.7×10^{6}
Calcium Phosphate	11.2×10^{6}	6.6×10^{6}	4.6×10^{6}	4.6×10^{6}	0
Calcium Sulfate	1.26×10^{8}	1.17×10^{8}	9.5×10^{6}	9.5×10^{6}	0
Chlorine/Caustic	9.8×10^{8}	2.0×10^{8}	2.5×10^{7}	7.8×10^{8}	7.6×10^{8}
Chrome Pigments	10.5×10^{6}	0	0	10.5×10^{6}	10.5×10^{6}
Hydrochloric Acid	16.6×10^{6}	0	16.6×10^{6}	16.6×10^{6}	0
Hydrofluoric Acid	18.4×10^{7}	8.3×10^{7}	1.3×10^{6}	1.0×10^{8}	9.9×10^{7}
Hydrogen Peroxide	15.1×10^{6}	3.8×10^{6}	0	1.1×10^{7}	1.1×10^{7}
Nitric Acid	4.6×10^{7}	0	2.4×10^{6}	4.6×10^{7}	4.4×10^{7}
Phosphoric Acid (dry)	11.3×10^{6}	0	11.3×10^{6}	11.3×10^{6}	0
Phosphoric Acid (wet)	3.1×10^{8}	2.77×10^{8}	3.3×10^{7}	3.3×10^{7}	0
Phosphorus	7.6×10^{6}	4.2×10^{6}	0	3.4×10^{6}	3.4×10^{6}
Plating Chemicals	2.1×10^{6}	0	2.1×10^{6}	2.1×10^{6}	0
Potassium Chloride	3.4×10^{6}	0	0	3.4×10^{6}	3.4×10^{6}
Sodium Carbonate	3.4×10^{7}	2.4×10^{7}	0	1.0×10^{7}	1.0×10^{7}
Sodium Chlorate	3.1×10^{6}	1.7×10^{6}	1.6×10^{5}	1.4×10^{6}	1.2×10^{6}
Sodium Chloride	6.0×10^{6}	0	6.0×10^{6}	6.0×10^{6}	0
Sodium Phosphate	8.2×10^{7}	4.9×10^{7}	0	3.3×10^{7}	3.3×10^{7}
Sodium Silicate	2.1×10^{6}	0	9.0×10^{5}	2.1×10^{6}	1.2×10^{6}
Sulfamic Acid	10.3×10^{6}	0	0	10.3×10^{6}	10.3×10^{6}
Sulfuric Acid	13.6×10^{8}	13.6×10^{6}	1.1×10^{7}	1.35×10^{9}	1.33×10^{9}
Titanium Dioxide	4.6×10^{8}	4.6×10^{7}	0	4.1×10^{8}	4.1×10^{8}
Zinc Oxide	9.5×10^{6}	0	0	9.5×10^{6}	9.5×10^{6}
Other**	1.0×10^{7}	5.7×10^{6}	0	4.5×10^{6}	4.5×10^{6}
Total	6.5×10^{9}	1.9×10^{9}	1.6×10^{8}	1.5×10^{10}	4.5×10^{9}

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* "0" indicates less than 2 percent of gross water use.

** Other includes two product segments (sodium borate decahydrate and sodium dichromate) that are produced at fewer than three plants nationwide.

TABLE 7

DISTRIBUTION OF MAJOR WATER-USING SEGMENTS BY REGION

WRC REGIONS	Alumina	Aluminum Sulfate	Ammonia	Ammonium Nitrate	Ammonium Sulfate	Calcium Oxide	Calcium Phosphate	Calcium Sulfate	Chlorine/Caustic	Chrome Pigments	Hydrochloric Acid	Hydrofluoric Acid	Hydrogen Peroxide	Nitric Acid	Phosphoric Acid (dry)	Phosphoric Acid (wet)	Phosphorus	Plating Chemicals	Potassium Chloride	Sodium Borate Decahydrate	Sodium Carbonate	Sodium Chlorate	Sodium Chloride	Sodium Dichromate	Sodium Phosphate	Sodium Silicate	Sulfamic Acid	Sulfuric Acid	Titanium Dioxide	Zinc Oxide	Total
1. New England		2			1	4	2	2	1		2							1				1				2		2			20
2. Middle Atlantic		9	2	1	6	11	3	14	3	7	1	11		4	2	1		6					1	1	2	8	1	18	4	1	117
3. South Atlantic	1	16	8	9	9	9	3	7	6		4			11	2	16	2					5	1	1	1	3		25	3		142
4. Great Lakes		7	1	1	9	19	1	11	9	3	5	1		2	3	1		6				2	13		3	11	1	13	2		124
5. Ohio		8	8	5	13	9	1	2	7	3	13	2	2	8	2			3				1	5		3	5		12		2	114
6. Tennessee		3	3	4		3		2	2		4			5			3											1	1		33
7. Upper Mississippi		4	7	9	1	3	5	5	1		3			12	2	3		1							3	2		15		2	78
8. Lower Mississippi	6	10	19	7	1	2		1	9		10	2	1	11		4						2	6			3		12			106
9. Souris-Red Rainy																							1								1
10. Missouri		1	6	6		2	2	11						7	1										1	1		4			42
11. Arkansas White-Red		1	11	8	1	2	1	6	2		2			6									7					7		1	55
12. Texas Gulf	2	2	9	3	6	7		4	9		11	2	2	9	2	2							10		1	1		11			93
13. Rio Grande			2	1	1			2	1					1					6				2					6			22
14. Upper Colorado																1			1		4				1						7
15. Lower Colorado			2	1	1	5		6	1		1			1								2	1					6			27
16. Great Basin		1	1	1	1	2		2						1		1							3					1			14
17. Columbia North Pacific		6	6	4	1	2		1	5		4		1	5	1	3	3					2				2		7			53
18. California South Pacific		7	9	5	5	3		2	1		5	1		6	3	4		1		1			4		4	4		10	1		76
19. Alaska			1																												1
20. Hawaii																												1			1
21. Caribbean	1																														1
Total	10	77	95	65	56	83	18	78	57	13	75	9	6	89	20	36	8	18	7	1	4	15	54	2	19	42	2	151	11	6	1127

MAXIMUM RECYCLE SIDESTREAM SOFTENING SYSTEM AT A PETROCHEMICAL PLANT

Wendy M. Gardiner
Research Engineer

Jack V. Matson
Associate Professor
Environmental Engineering Program
University of Houston
Houston, Texas 77004

INTRODUCTION

The University of Houston Environmental Engineering Program is currently conducting a two-year research grant entitled "Demonstration of a Maximum Recycle, Sidestream Softening System at a Petrochemical Plant." At the petrochemical plant under study, the water system is unique in that the only effluent discharged is a high TDS demineralizer regeneration stream (refer to Figure 1 for water system schematic). Water that was previously blown down from the cooling towers on an intermittant basis is now continously recycled. The new treatment system takes a sidestream off the heat exchangers of two cooling towers to the two softeners. Major precipitates in this unit are calcium carbonate and a magnesium hydroxide-silica complex. A lime slurry is added to raise the pH to approximately 10 while th soda ash added provides the carbonate species to precipitate the calcium ion in the water. The softener overflows are then acidified by carbon dioxide gas injection in two stages of the recarbonator to a mean effluent pH of 9.8. The softened water is then filtered to remove any small particulates which did not settle in the softener or recarbonator units, and then returned to the top of the cooling towers. As this system uses CO_2 to maintain cooling water pH, the water is supersaturated with respect to this gas. Thus, CO_2 is continually stripped out in the cooling towers and must be injected into the cooling water before the cold water return to the exchangers. As shown in Fig. 1, there are several other recycle streams to the cooling towers, some of which are processed in the wastewater treatment unit.

The purpose of this paper will be to elucidate the operational and chemical aspects of this cooling water recycle system. Attention will be given to the following areas: major water stream qualities and chemical costs of the lime/soda ash system. Topics also included will be sludge leachate testing, optimization projects, and anticipated further work.

PLANT SOFTENER LABORATORY DATA

The crucial factors for operators to monitor in both the cooling water and sidestream softener systems are the calcium hardness (CaH), alkalinity, and pH. For the first system, the combined levels of CaH and alkalinity should be controlled to within an acceptable limit to prevent scaling on heat exchanger surfaces. Control of pH is essential to prevent the formation of the carbonate ion and hence to lessen scaling tendencies in the cooling water system. The objectives of the operators here are to achieve a stoichiometric balance in the softener between the carbonate and calcium hardness concentrations for optimum softener efficiency with a corresponding maintenance of pH in the vicinity of 10.3.

A trend analysis was performed on the above variables for the eight-month period from September 1, 1980 through April 30, 1981. This was done by calculating a 21-day moving average for the 242-day period. As there were no continuous increasing or decreasing trends, the systems can be appropriately described by reporting their means, standard deviations, and confidence intervals. These results are shown in Table 1. The confidence interval and standard deviation formulas used indicate respectively that there is a 95.5% chance that the true mean is included in the range and that 95.5% of the area under the normal curve is included. It is assumed that the distribution function of the data followed a Gaussian distribution. Below is a summary of the formulas used in statistical calculations.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

$$SD = \sqrt{\frac{\sum_{i=1}^{n} x_i^2}{n} - \bar{x}^2}$$

$$CI = \bar{x} \pm z\frac{SD}{\sqrt{n}}$$

where $\bar{x}$ = mean
x_i = the i the measurement
n = number of measurements
z = a constant determining the width of the confidence interval

There are several interesting and valid questions to ask of the data. Firstly, is there an effect of softener pH on recarbonator effluent, i.e., is a greater removal of calcium through the softeners demonstrated by an increase in pH? The correlation coefficient of a plot of influent cooling water CaH* minus recarbonator CaH versus average softener pH showed almost no influence of CaH on softener pH. One factor that can obscure the above relationship in this analysis is that a higher softener pH can be obtained through use of additional lime ($Ca(OH)_2$) for a constant concentration of those species [1] requiring the hydroxide ion. This in turn generates an incease in CaH influent to the softeners. If the water quality with respect to these species does change and if, therefore, the amount of lime necessary to maintain constant softener pH also changes significantly, then the amount of CaH removed across the softener is difficult to determine. Hence, there might not be seen as clear a relation in the comparison of pH versus CaH removal. As the purpose of this report is to provide viable operating data, analyses of this type will be forthcoming at the project's termination.

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*Obtained by a flow weighted average of influent cooling waters.

UNIVERSITY-DETERMINED WATER QUALITIES

Comprehensive sampling and analysis of the different streams within the petrochemical plant were performed on several different occasions. Table 2 shows the average of these results. Methods of analysis used were as per Standard Methods, 14th ed. The accuracy of these values were internally scrutinized by checking the percent agreement of cations and anions in the individual water qualities. In the few cases in which this error was unreasonably high, the Na^+ or K^+ concentrations were questionable. The preciseness of those concentrations was hard to obtain, as up to 1000-fold dilutions must be made to measure the concentrations on the 0-5 ppm range of a flame atomic absorption unit. If, in the duration of the analysis time, the standard curve "drifts," then the end results would not be repeatable, nor probably accurate.

On February 17, 1981, samples from eight streams and four sludge locations were split between the University of Houston laboratory and the E.P.A. laboratory in Ada, Oklahoma. A comparison of the results is shown in Tables 3 and 4.

One important point in method of analysis concerns the need to filter samples for an alkalinity determination. In some water streams within the plant, the amount of $CaCO_3$ fines present will significantly raise the total "M" alkalinity present. Tables 5 presents a comparison of filtered and non-filtered samples.

A second external check procedure for quality assurance of the chemical analysis is performed through the Water and Wastewater Analysts Association. Twice annually, a set of unknown mineral samples from the WWAA are analyzed at approximately thirty laboratories in the Houston area, including our laboratory. All of the results from a March, 1981 sample tested at the University of Houston labortory fell within an acceptable error range (two standard deviations, which was based on the results of participating laboratories).

COMPARISON OF EPA EXTRACTION PROCEDURE WITH TEXAS LEACHATE TEST

Recent federal guidelines [2] mandate the safe disposal of the variety of solid wastes generated by industrial plants. Antecedent to the determination of disposal methods used are the toxicity levels of the waste and the tests employed to measure them. A study was performed to determine the differences in chromium toxicity levels resulting from the U.S. EPA extraction procedure (EP) and the Texas Solid Waste Evaluation Leachate Test (see Reference 2 and Figure 2 for respective test procedures). Data is also presented here on the leachate tests on the softeners and thickener. Figure 3 shows a simple schematic of the waste solids flow. For an evaluation of the lime sludge distinct from that of the raw water clarifiers, samples of the former sludge were filtered to obtain a cake approximating that which is landfilled. The same leachate tests were run on the lime sludge filter cakes. Figure 4 shows the results of both hexavalent (Cr^{+6}) and trivalent (Cr^{+3}) chromium concentrations for two separate sludge samplings.

Two features immediately outstanding from the data are that (1) chromium concentrations obtained in the EPA test are much lower than those obtained in the Texas test and (2) the marked decrease in chromium concentrations as the sludge proceeds from the softeners and emerges as filter cake to be landfilled. The latter observation is explained by the process of diluting the sludge from the softened cooling water with that of raw river water.

The EPA test utilizes only a 24-hour period with the addition of acetic acid while the Texas test is run for a one-week period with no acid addition. Apparently, for this particular lime sludge, a longer exposure time results in a higher chromium concentration. There is also quite a variability in the ratio of hexavalent chromium (which is regarded as the toxic form of chromium) to total chromium. In no case, however, did the concentrations exceed the 5.0 ppm level mandated by the federal government [3].

CHEMICAL USAGE AND COST RATES

Concurrent with analysis of operating parameters of the lime softening water system, a cost analysis should be included in a feasibility study. Chemical costs per 3.785×10^6 gallons and per 10^6 liters for the lime softening system (lime, soda ash, CO_2, and sludge disposal) are shown for a set of four three-week periods in Table 6. Calculations for these parameters were done by amount used and an inventory check and were based on current unit prices. The lime calculations took into account the amount of dilution water added to new lime slurry shipments. CO_2 consumption was split between the cooling towers and the recarbonator, with the majority going to the first units. Design rate was set at 1000 lbs per day (453.6 kg per day) to the recarbonator and this figure was assumed for consumption rate calculations. Consequently, the consumption rate of the cooling water was decreased by the 1000 lbs per day. Best estimates at present gave a split of 50-50 for the pounds of filter cake produced between the raw water clarifiers and the lime softeners. Carbon dioxide unit costs have increased considerably while sludge disposal costs have dropped due to a reclassification of the waste by Texas Department of Water

Resources (TDWR) guidelines to a non-toxic category. Future cost calculations will be based upon these current prices, although noting the percentage increase in cost due to further increases in unit costs of chemicals. An average cost of $375.0 per 10^6 gallons ($99.0 per 10^6 liters) was obtained, with lime comprising 55 percent of that cost.

BIOFOULING CONTROL

In the first months of 1981, an increasing problem of biofouling in the cooling towers was noted. In a recycle system with high concentrations of dissolved solids and organics, microorganism growth is not as nutrient-limited as it would be in a lower TDS system. Increased system corrosion and loss of heat transfer efficiency in the heat exchangers are potential repercussions from this type of deposition. At that point, high bromine concentration was used exclusively to significantly reduce the fouling. Then, stepwise increases in the cooling watr concentrations of chlorine and bromine were made until a halogen level at which the microbe population could be controlled, was determined. On a weight basis, bromine is more costly than chlorine. Therefore, an optimum dosage of the two chemicals was sought in which the bromine addition was minimized. At a Cl to Br ratio of 10 to 1 with total halogen concentration equaling 0.45 mg/L, biofouling was significantly reduced. These dosage levels currently comprise the biofouling maintenance system at the plant.

FURTHER WORK

Cost analysis, concurrent with computer analysis of system performance, will comprise a part of the evaluation of this recycle system. The demarkation of analysis periods depends upon those periods chosen in the cost study.

Costs were calculated manually as the data input was under constant modification (method of addition, inventories, etc.) and did not lend itself to computer programming. Automatic computation would become more feasible when optimization of chemical additives had stabilized. A comparison between caustic soda and lime softening will be possible when the feed system of the former is installed. Theoretically, with caustic soda softening, there is no need to add soda ash. This is due to the fact that the excess calcium added as lime requires additional carbonate ions for a balanced stoichiometric reaction. Sodium concentrations would remain constant also. The amount of Na^+ added as NaOH is double that of $Ca(OH)_2$. However, assuming the calcium and carbonate concentrations are equal (as mg/L $CaCO_3$) in the cooling water, CO_3 of the Na_2CO_3 is no longer needed to balance the Ca in the lime. This decreases the amount of sodium added by the same amount increased through use of caustic soda. Dependent on the chmical unit prices for the above, there are potential cost savings when soda ash is eliminated and when caustic soda replaces lime.

Further testing of leaching properties of the sludges is planned. One question to answer is does the sludge act in any capacity to remove chromium from the liquid phase by an adsorption mechanism, and, if so, at what liquid concentraton of chromium will the leachate chromium obtained from the sludge exceed the 5.0 ppm level. A second interesting aspect to be investigated is the chromium concentrations during the extraction procedures. Here, the 24-hour EPA test could be extended for as long as the Texas test and periodic analyses run on the leachate for chromium concentration. The concentrations of chromium species in different valences depends upon pH, reducing and oxidation conditions [4]. As pH is also monitored during the EPA 24-hour extraction period, an examination into the effect of pH on chromium species distribution would provide more insight into the character of the lime sludge.

A model specific to present operational conditions is currently under development. The model will be used to forecast changes in the cooling and softening systems induced by changes in flow rates, dose and nature of chemicals, pH, and softener solids recycle. By assuming reactor volume, makeup water quality, and temperature to be fixed system inputs, softened water (or cooling water) quality and cost can be determined. Opportunity also exists here for the modification of current sidestream softening theory by the incorporation of new theories to explain actual plant performance. One significant point in the analysis of softener performance concerns the amount of alkalinity due to the carbonate species. At present, lime and soda ash dosages are based upon operator tests of CaH and alkalinity. However, it has been preliminarily found that in the alkalinity measurement (in which it is assumed that 100 percent of the alkalinity is due to the carbonate species, a large percent is attributable to organic acids. A good estimate of the bicarbonate alkalinity would give a better and probably lower estimate for lime dosage. Savings in chemical cost and better cooling water quality are possible benefits from this alkalinity investigation.

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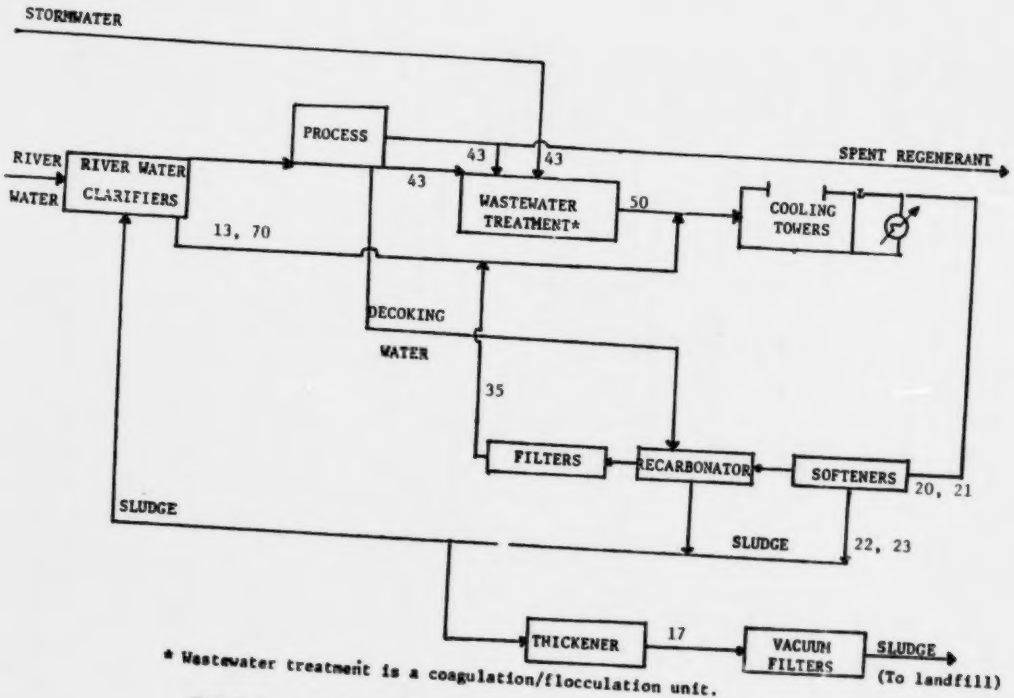
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43
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SPENT REGENERANT
WASTEWATER TREATMENT*
50
COOLING TOWERS
13, 70
DECOKING WATER
35
FILTERS
RECARBONATOR
SOFTENERS
20, 21
SLUDGE
SLUDGE
22, 23
THICKENER
17
VACUUM FILTERS
SLUDGE
(To landfill)

* Wastewater treatment is a coagulation/flocculation unit.

FIGURE 1. PROCESS FLOW SCHEMATIC OF THE MAXIMUM RECYCLE, SIDESTREAM SOFTENING SYSTEM

Solid Waste Evaluation Leachate Test

1. A 150 gm. (dry weight) representative sampe of the waste material should be taken and placed in a 1500 ml. Erlenmeyer flask.

2. One liter of deionized or distilled water should be added to the flask and the material stirred mechanically at a low speed for five (5) minutes.

3. Stopper the flask and allow to stand for seven (7) days.

4. Filter the supernatant solution through a .45 micron filter.

5. The filtered leachate from (2) should be subjected to a quantitative analysis for those component or ionic species determined to be present in the analysis of the waste itself.

Note: Triplicate samples of the waste should be leached in order to obtain a representative leachate.

FIGURE 2

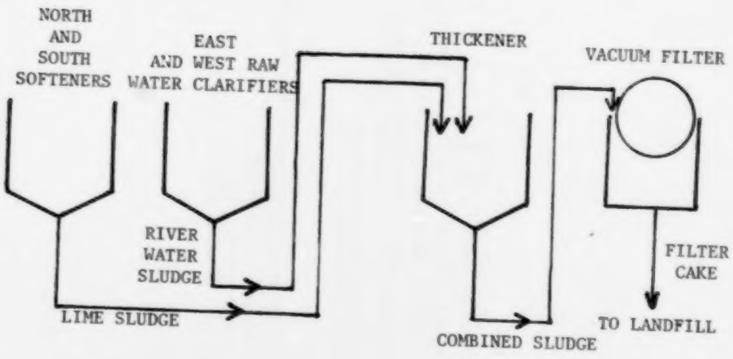

NORTH AND SOUTH SOFTENERS
EAST AND WEST RAW WATER CLARIFIERS
THICKENER
VACUUM FILTER
RIVER WATER SLUDGE
LIME SLUDGE
COMBINED SLUDGE
FILTER CAKE
TO LANDFILL

FIGURE 3. WASTE SOLIDS FLOW

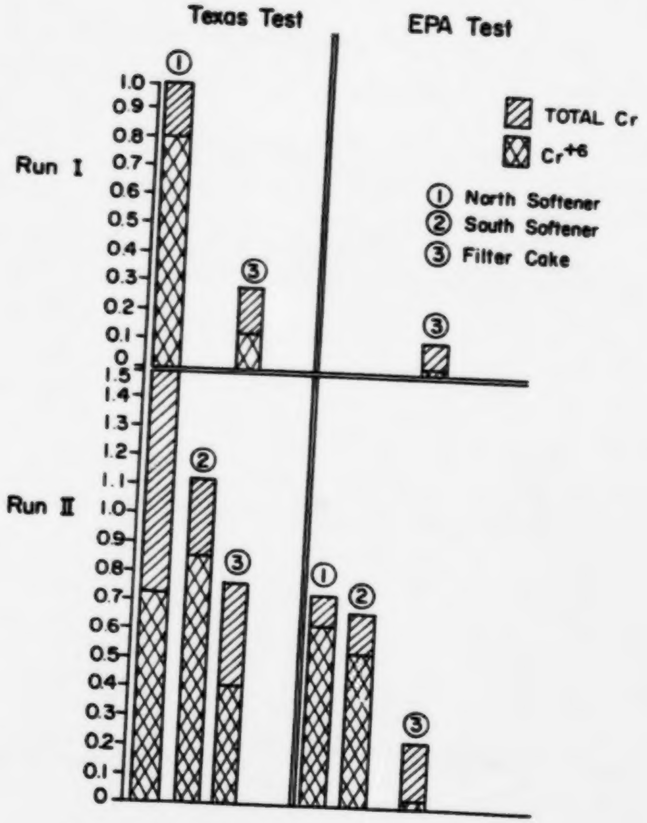


FIGURE 4
EPA AND TEXAS
CHROMIUM LEACHATE RESULTS

TABLE 1. COOLING AND SOFTENING SYSTEM AVERAGES[*]
SEPTEMBER 1980 THROUGH APRIL 1981

	Calcium Hardness (ppm $CaCO_3$)			Alkalinity (ppm $CaCO_3$)			pH		
	Mean	Standard Deviation	Confidence Interval	Mean	Standard Deviation	Confidence Interval	Mean	Standard Deviation	Confidence Interval
Ethylene Cooling Tower	250.5	47.9	247.4 - 253.7	362.1	99.7	355.5 - 368.8	7.46	7.28 - 7.77	7.44 - 7.47
Styrene Cooling Tower	268.5	33.2	266.3 - 270.6	262.0	67.9	257.7 - 266.4	7.39	7.21 - 7.72	7.38 - 7.41
North Softener	120.8	44.3	118.9 - 122.7	109.7	31.2	108.1 - 111.2	10.25	10.02 - 10.76	10.24 - 10.27
South Softener	120.2	52.9	117.7 - 122.8	111.8	23.6	110.7 - 112.9	10.23	9.97 - 10.93	10.21 - 10.24
Recarbon-ator	101.6	31.2	99.5 - 103.6	216.7	41.6	214.0 - 219.4	8.21	7.97	8.17 - 9.26

---

[*] See page 3 for formulas used in calculating mean, standard deviation, and confidence level.

TABLE 2 . AVERAGE WATER SYSTEM SAMPLE ANALYSIS[*]

Location[§]	No.	Ca^{2+}[†]	Mg^{2+}[†]	K^+	Na^+	Cl^-	SO_4^{2-}	TAlk[†]	SiO_2	pH	TDS	Turbidity (NTU)	TSS	TOC
Treated Raw Water	13	108	14.8	13.6	34.6	45.8	38.4	76.5	8.7	7.74	209.5	2.5	85.5	7.4
Ethylene Influent to Softener	20	276	29.5	343	9,175	11,100	6,453	391	62.2	7.40	22,609	42.8	256	548.2
Styrene Influent to Softener	21	282	35.0	180	5,975	6,444	4,000	286	44.7	7.52	13,721	12.0	141	328.0
Combined Filter Effluents	35	110	8.6	434	7,750	8,442	5,453	258.5	46.1	8.32	24,214	21.1	182.5	476.0
Guard Basin Effluent	43	126	15.0	135	2,887	2,971	1,569	187.3	22.6	8.90	5,140	44.4	143.0	214.5
WWTU Effluent	50	72	8.0	41	7,075	1,099	1,000	90	10.6	7.51	3,622	41.6	91.5	121.0
M-1008	70	108	14.8	13.6	34.2	45.8	36.8	76.5	8.2	7.5	354	6.0	85	7.8

[*] All values in mg/l unless otherwise noted

[†] Values in mg/l $CaCO_3$

[§] Refer to Figure 1 for location of sample point in water system

TABLE 3 SPLIT SAMPLE ANALYTICAL RESULTS*

Parameters mg/1		SAMPLE 13	20	21	25	43	50	70	17 filtrate	22 filtrate	23 filtrate
Ca	UH	38	94	100	34	60	28	19	64	60	61
	EPA	37	76	83	32	41	24	37	70	43	47
Mg	UH	3.6	7.8	8.8	2.4	5.6	2.6	1.8	24	1.0	.38
	EPA	3.8	2.1	8.5	2.3	4.0	2.5	3.8	19	1.7	.99
Na	UH	8	8600	4800	9600	6400	3750	10	2750	9900	8700
	EPA	28	9550	4300	8100	2400	1430	29	2150	7880	7840
K	UH	2.1	478	250	425	158	80	3.1	138	472	458
	EPA	4.1	647	290	555	180	88	4.3	148	565	559
Cr	UH	--	--	--	--	--	--	--	.04	1.4	1.3
	EPA	<.01	0.9	7.5	8.4	2.9	.97	<.01	1.4	8.6	8.8
TSS	UH	34	1270	3460	6580	3080	1380	38	--	8250	41430
	EPA	6	36	18	36	18	18	6	16	77	42
TDS	UH	276	0600	11060	21680	5980	3550	272	--	23310	19970
	EPA	436	1020	14350	28050	8430	4800	222	7630	27910	28050
Cl	UH	46	1620	4830	9680	3010	1590	46	2490	9660	9720
	EPA	52	0930	4990	8570	2980	1590	50	2720	9650	9790
SiO_2	UH	9.0	9.0	49.0	61.5	30.5	16.0	9.0	13.5	57.0	40.[illegible]
	EPA	-	-	-	-	-	-	-	-	-	-
SO_4	UH	32	8000	3620	6800	2180	1200	34	1700	7000	6880
	EPA	33	8240	3660	5790	2520	1460	35	1990	5650	5450
TOC	UH	3.0	453	238	356	185	93	2.0	230	423	404
	EPA	6	520	242	450	234	120	5	204	447	467
pH	UH	7.5	7.8	7.6	8.8	9.1	7.6	7.5	--	11.0	11.1
	EPA	7.5	7.9	7.6	8.7	9.1	7.8	7.7	9.4	10.8	10.8
Alkalinity ($CaCO_3$)	UH	171	1060	738	722	588	278	171		776	760
	EPA	85	514	360	348	288	132	78	96	366	366

*For location of sample points, refer to location of sample number in Figure 1

TABLE 4 . ION BALANCE

Sample Number										
UH	13	20	21	35	43	50	70	17 Filtrate	22 Filtrate	23 Filtrate
Total Cation	2.59759	391.47958	220,81319	430.41400	285.76233	166.70332	1.61209		445.58865	393.05566
Total Anion	5.38116	515.63306	226.41148	430.82086	142.07430	75.40685	5.42283		433.83569	432.70853
Cation-Anion	-2.78357	-124.15347	-5.59830	-0.40686	143.68803	91.29647	-3.81073		11.75296	-39.65286
% Agreement C/A	48.27188	75.92213	97.52738	99.90556	201.13585	221.07184	29.72791		102.70908	90.83613
EPA										
Total Cation	3.48475	436.14856	199.22243	368.15744	111.33036	65.83014	3.53334	102.32593	359.34863	357.59766
Total Cation	3.85281	490.25891	224.20508	369.32761	142.31682	77.90617	3.69819	120.10437	397.23608	397.01862
Cation-Anion	-0.36806	-54.11035	-24.98265	-1.17011	-30.98646	-12.07603	-0.16484	-17.77844	-37.88745	-39.42096
% Agreement C/A	90.44701	88.9629	88.85723	99.68317	78.22713	84.49927	95.54264	85.19751	90.46223	90.07076

TABLE 5. TOTAL ALKALINITY (mg/L $CaCO_3$)

Sample No.	Filtered	Non-Filtered
13	78	76
20	394	458
21	302	305
35	212	282
43	225	216
50	112	112
70	76	76

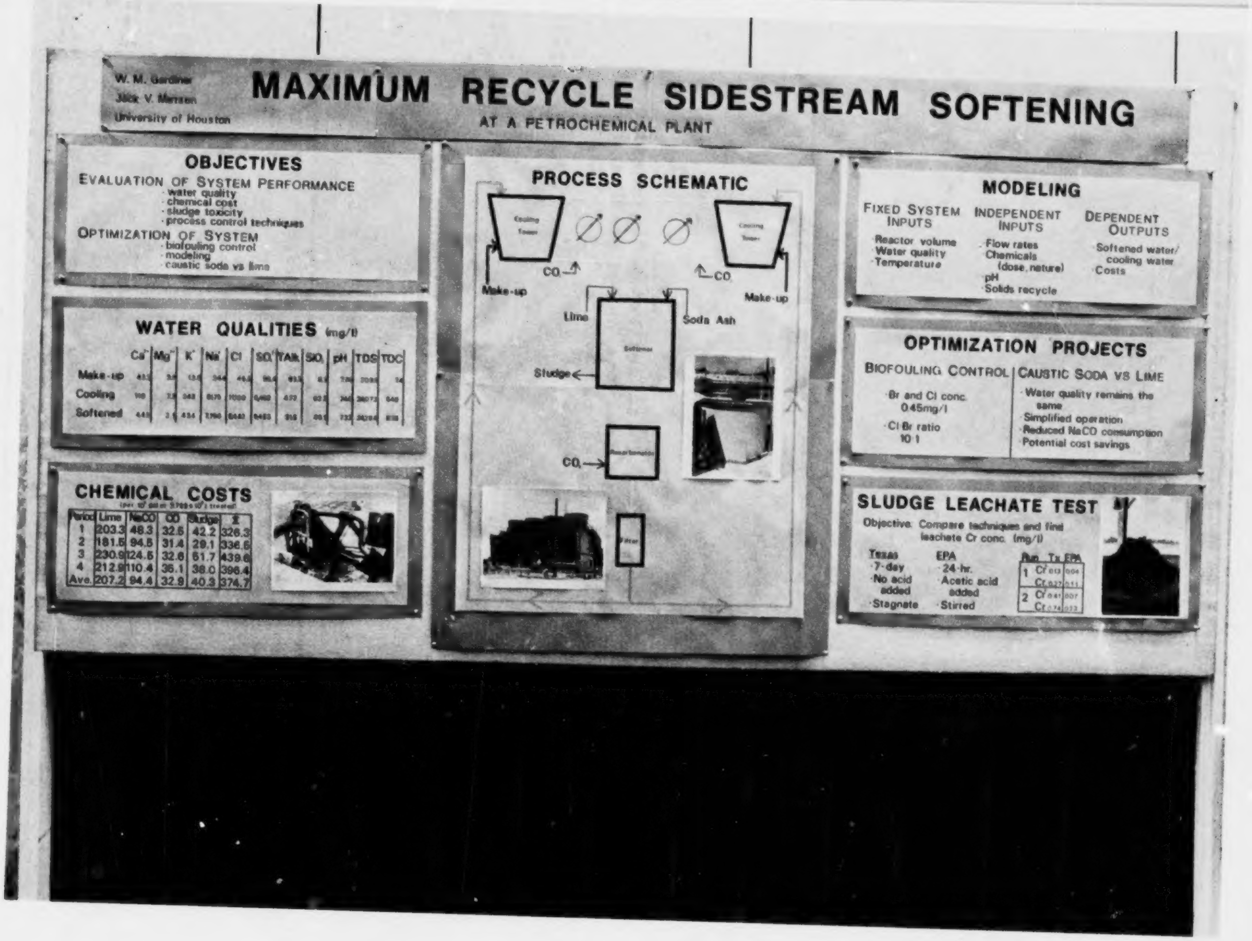
Sample Treatment: Normality of Acid
$pH_{initial} = 8.3$
$pH_{final} = 4.50$

Depending upon the amount of undissolved $CaCO_3$ present, the alkalinity can vary as seen from the above results. We recommend filtration of samples through a 0.45 filter before the titration to pH_{final} 4.5.

TABLE 6. CHEMICAL COST $/10^6$ GALLONS[1]
($/3.785 X 10^6 LITERS)

Date	Lime	Soda Ash	CO_2	Sludge	Cost
3/5-3/25	203.3	48.4	32.5	42.2	326.3
3/26-4/15	181.5	94.5	31.4	29.1	336.5
4/16-5/6	230.9	124.5	32.6	51.7	439.6
5/7-5/27	212.9	110.4	35.1	38.0	396.4
Ave. Cost	207.2	94.4	232.9	40.3	373.4

[1] Treated water



W. M. Gardiner
Jack V. Matson
University of Houston

MAXIMUM RECYCLE SIDESTREAM SOFTENING

AT A PETROCHEMICAL PLANT

OBJECTIVES

EVALUATION OF SYSTEM PERFORMANCE
- water quality
- chemical cost
- sludge toxicity
- process control techniques

OPTIMIZATION OF SYSTEM
- biofouling control
- modeling
- caustic soda vs lime

WATER QUALITIES (mg/l)

	Ca⁺⁺	Mg⁺⁺	K⁺	Na⁺	Cl	SO₄	TAlk	SiO₂	pH	TDS	TOC
Make-up	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Cooling	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Softened	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

CHEMICAL COSTS

Period	Lime	NaCO	CO	Sludge	Σ
1	203.3	48.3	32.5	42.2	326.3
2	181.5	94.5	31.4	29.1	336.5
3	230.9	124.5	32.6	51.7	439.6
4	212.9	110.4	35.1	38.0	396.4
Ave.	207.2	94.4	32.9	40.3	374.7

PROCESS SCHEMATIC

MODELING

FIXED SYSTEM INPUTS	INDEPENDENT INPUTS	DEPENDENT OUTPUTS
Reactor volume Water quality Temperature	Flow rates Chemicals (dose, nature) pH Solids recycle	Softened water/cooling water Costs

OPTIMIZATION PROJECTS

BIOFOULING CONTROL	CAUSTIC SODA VS LIME
Br and Cl conc. 0.45mg/l Cl:Br ratio 10:1	Water quality remains the same Simplified operation Reduced NaCO consumption Potential cost savings

SLUDGE LEACHATE TEST

Objective: Compare techniques and find leachate Cr conc. (mg/l)

Texas	EPA
7-day	24-hr.
No acid added	Acetic acid added
Stagnate	Stirred

Run		Tx	EPA
1	Cr	[illegible]	[illegible]
	Cr	[illegible]	[illegible]
2	Cr	[illegible]	[illegible]
	Cr	[illegible]	[illegible]

PB82-223546

STUDY OF THE POTENTIAL FOR WATER REUSE IN THE STEEL INDUSTRY

Dominick D. Ruggiero - Vice President,
Hydrotechnic Corp.
Ivan Pouschine, Jr. - Executive Vice President,
Hydrotechnic Corp.
Harold Hofstein - Manager Engineer, Hydrotechnic Corp.
1250 Broadway
New York, NY 10001

I. INTRODUCTION

Water scarcity implies a supply to demand ratio of less than one, where competing users exert a demand for limited supplies of similar quality water. Competing uses vary regionally in their importance according to such factors as agricultural, industrial, and population needs. Supply alternatives may be dependent upon ground or surface water quality, local aridity, over-draft of ground water sources and inadequate structural or non-structural water resource planning and other factors.

A 1978 Water Resources Council (WRC) study quantified the nature of the problem and concluded that while the nation's water supplies generally are sufficient to meet the requirements for all purposes, there are major water supply problems in most of the 106 subregions studied. These problems include: shortages resulting from inadequate distribution systems, ground water overdrafts, quality degradation of both surface and underground supplies and institutional constraints.

The WRC study concludes that the problem of inadequate water supply is currently severe in 14 of the 106 subregions, located mainly in the Southwest and Midwest. It projects that by the year 2000 inadequate supplies will be a problem in 24 subregions. Severe domestic rural water supply shortages were identified in half of the 106 subregions. Reuse and recycle constitute means to alleviate these problems of water scarcity.

As is widely recognized, the steel industry is a major user of water. A recent study for the Office of Water Research and Technology of the United States Department of the Interior (OWRT) showed that steelmaking is the single largest user among manufacturing categories and estimated that nearly 15 billion gallons per day of fresh water are abstracted by the industry. Since the steel industry in the United States is the single largest industrial user of water, and since steel plants are located in 11 of the 18 water regions of the United States, it was selected for a study of the potential for water reuse by the Department of the Interior's Office of Water Research and Technology. This technical paper presents a summary of the study.

II. THE STEEL INDUSTRY

The United States Steel Industry consists of integrated, mini and median steel plants and specialty shops. The integrated steel plants, which produce over 85 percent of the raw steel in the United States, generally produce finished steel products from ore, coal, special additives and lime. These plants are traditionally located along major bodies of water to obtain inexpensive water transportation and to have an ample supply of water for plant use. Figure 1 shows the location of the 50 largest integrated steel plants in the United States. Most of these integrated steel plants are located in Northeastern United States.

Since integrated steel plants account for most of the steel production in the United States, and since small steel installations normally consist of one or more of the production facilities found in an integrated steel plant, the integrated steel plant was utilized as the basis for this study.

An integrated steel plant was defined as including, as a minimum, the following facilities:

1) A coke and by-products plant
2) A sinter plant
3) One or more blast furnaces
4) Basic oxygen steel making
5) Hot forming mills
6) Cold finishing mills
7) Service facilities for ancillary products and utilities

Figure 2 shows a typical process flow of materials and products within a four million ton per year integrated steel plant.

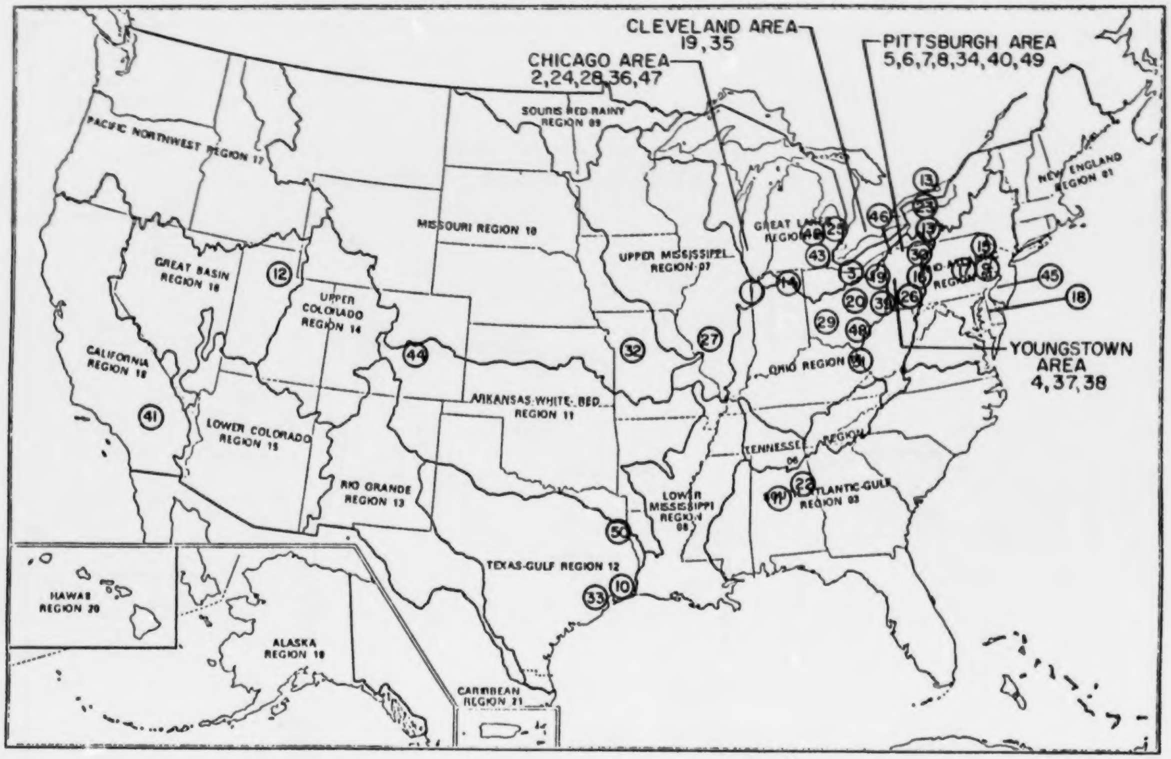
As described above, a typical integrated steel plant is comprised of many different manufacturing facilities. Each of these requires a particular quality and quantity of water. The water uses can be generally classified as follows:

Direct Cooling Water Systems
Indirect Cooling Water Systems
Potable Water System
Service Water System
Demineralized Water System
Stormwater System

The various systems outlined above can be defined as:

Direct Cooling Water Systems

This water is used in direct contact applications for iron and steel making, gas washing and cooling, descaling and cooling of product, flushing flumes and for washing of equipment and product. During these processes, the water becomes laden with particles of iron oxide and steel, along with oils and greases, as well as other chemicals in steel finishing.


CLEVELAND AREA
19,35
PITTSBURGH AREA
5,6,7,8,34,40,49
CHICAGO AREA
2,24,28,36,47
YOUNGSTOWN AREA
4,37,38
SOURIS-RED-RAINY REGION 09
PACIFIC NORTHWEST REGION 17
MISSOURI REGION 10
UPPER MISSISSIPPI REGION 07
GREAT LAKES REGION 04
NEW ENGLAND REGION 01
MID-ATLANTIC REGION 02
GREAT BASIN REGION 16
UPPER COLORADO REGION 14
CALIFORNIA REGION 18
LOWER COLORADO REGION 15
ARKANSAS-WHITE-RED REGION 11
OHIO REGION 05
TENNESSEE REGION 06
SOUTH ATLANTIC-GULF REGION 03
LOWER MISSISSIPPI REGION 08
RIO GRANDE REGION 13
TEXAS-GULF REGION 12
HAWAII REGION 20
ALASKA REGION 19
CARIBBEAN REGION 21
1
3
9
10
11
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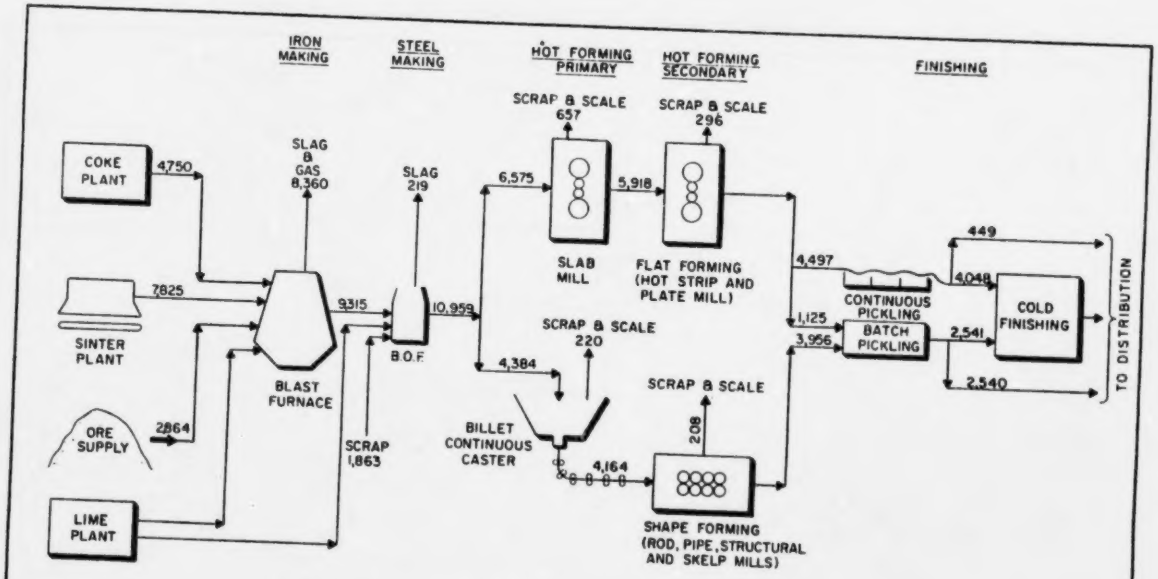
46
48
50

Figure 1 Location of 50 Largest Integrated Steel Plants by Water Resources Council Regions


IRON MAKING
STEEL MAKING
HOT FORMING PRIMARY
HOT FORMING SECONDARY
FINISHING
COKE PLANT
4,750
SINTER PLANT
7825
ORE SUPPLY
2864
LIME PLANT
SLAG & GAS 8,360
BLAST FURNACE
9315
SCRAP 1,863
SLAG 219
B.O.F.
10,959
6,575
4,384
SCRAP & SCALE 657
SLAB MILL
5,918
SCRAP & SCALE 296
FLAT FORMING (HOT STRIP AND PLATE MILL)
SCRAP & SCALE 220
BILLET CONTINUOUS CASTER
4,164
SCRAP & SCALE 208
SHAPE FORMING (ROD, PIPE, STRUCTURAL AND SKELP MILLS)
4,497
1,125
3,956
CONTINUOUS PICKLING
BATCH PICKLING
449
4,048
2,541
2,540
COLD FINISHING
TO DISTRIBUTION

MATERIAL FLOW DIAGRAM

(4 MILLION INGOT TONS PER YEAR INTEGRATED STEEL PLANT)

NOTES:

1. ALL FIGURES IN TONS/DAY
2. SCRAP AND SCALE MAY BE RECYCLED TO PRECEDING FACILITIES OF THE PLANT

Figure 2

Indirect Cooling Water Systems

Indirect or non-contact cooling water is used for furnace cooling at the blast furnaces, for machine and mold cooling at continuous casters, and the reheat furnaces, motor room and lubricant cooling of rolling mills. Power and boiler houses are also major users of indirect cooling water.

Potable Water System

A potable water system is required to furnish the different facilities within the steel plant with drinking water, sanitary, and process purposes such as solution makeup at plating lines.

Service Water System

Service water is used as makeup water to compensate for operating losses in the recirculating systems, and also is usually used for fire protection.

Demineralized Water System

Demineralized water is of high quality and is used in the boiler house. It may also be used in process equipment, depending on the type of equipment used (for example, BOF hood and lance, caster mold cooling, etc.).

Stormwater System

Stormwater and other land drainage can be, but generally is not, collected separately from other wastewater discharges and used for non-critical applications such as slag cooling.

III. WATER REQUIREMENTS AND DISCHARGES AT STEEL PLANTS

For the purpose of this paper, the water qualities applied to the production and service facilities at an integrated steel plant have been generally categorized. Table 1 describes the basic characteristics of water used for makeup, and assigns quality identifications based on use. Table 2 shows the water quality priorities for production and service facilities in decreasing order of quality. Then following are the general volumes of water requirements for each facility.

Coke making and by-products plants require between 3500 to 11,500 gallons per ton of coke produced. The volume of water used is a function of the extent of by-product recovery and processing, as well as the design of specific units.

Sinter plants require relatively low quantities of water which are utilized for sinter mix, cleaning of air and exhaust gases and for indirect cooling of the equipment. The volume of water utilized in sintering and gas cleaning ranges from 30 to 75 gallons per ton of sinter produced,

TABLE 1

CATEGORIES OF ESTIMATED WATER QUALITY DISCHARGED AT INTEGRATED STEEL PLANTS

AFTER BPT LEVEL TREATMENT

Category	Source	PARAMETERS*					
		pH	Total Dissolved Solids	Suspended Solids	Oil	Chloride	Total Hardness (as $CaCO_3$)
D-I	SANITARY	6-9	-	20	-	-	-
D-II	OPEN CIRCUIT NON-CONTACT COOLING**	6-9	450	15	2	150	350
D-III	CONTACT COOLING & GAS CLEANING						
-a	- Spray	6-9	600	20	10	150	350
-b	- Blast Furnace & BOP Gas	6-9	3500	50	5	800	1000
-c	- Coke Plant Gas	6-9	3500	50	15	800	350
D-IV	PROCESS						
-a	- Cold Rolling		900	25	10	50	300
-b	- Pickling	6-9	1500	50	10	1200	130
-c	- Cleaning	6-9	1500	25	10	50	1000
	ASSUMED RAW WATER MAKEUP		165	5	<1	50	130

*All Parameters except pH in mg/l.
**Assuming 2.7 cycles of concentration.

TABLE 2

INTEGRATED STEEL PLANT

PRIORITY WATER QUALITY REQUIREMENTS FOR DIFFERENT PROCESSES

(IN DECREASING ORDER)

		Makeup Category
(1)	Billet Cont. Caster - Mold Cooling	U-I
(2)	Misc. & Sanitary	U-I
(3)	Lime Plant	U-I
(4)	Billet Cont. Caster - Machine Cooling	U-I
(5)	Generator Station	U-II
(6)	B.O.F. - Non-Contact Cooling	U-II
(7)	Blast Furnace - Non-Contact Cooling	U-II
(8)	Flat Forming - Non-Contact Cooling	U-II
(9)	Oxygen Plant	U-II
(10)	Cold Finishing - Cold Processing	U-IV-a
(11)	Cold Finishing - Pickling	U-IV-b
(12)	Shape Forming	U-III-a
(13)	Billet Cont. Caster - Spray Cooling	U-III-a
(14)	Sinter Plant	U-III-a
(15)	Slab Mill	U-III-a
(16)	Flat Forming - Contact Cooling	U-III-a
(17)	By-Products Plant - Final Cooling	U-III-b-2
(18)	By-Products - Primary Gas Cooling & Benzol Plant	U-III-b-2
(19)	Blast Furnace - Contact Cooling	U-III-b-1
(20)	B.O.F. - Contact Cooling	U-III-b-1
(21)	Coke Plant	U-V
(22)	Materials Storage	U-VI

while water utilized for air cleaning generally ranges from 104 to 340 gallons per ton of production.

Water is used in the blast furnace (Iron Making Section) area of the steel plant for non-contact cooling of the furnaces and for contact cooling and cleaning of the gases produced. In general, approximately 5,030 gallons per ton of iron produced and applied to the blast furnace for non-contact cooling and the water utilized for gas cleaning and cooling range from 1500 to 4100 gallons per ton of production, depending on the gas cleaning facilities installed.

Water utilized in steel making will depend on the type of production facility utilized, whether open hearths, basic oxygen furnaces or electric furnaces. The volume of water required for non-contact cooling ranges from 460 to 11,470 gallons per ton of production and gas cooling and cleaning ranges from 50 to 2880 gallons per ton of production.

The water utilized in the hot forming section of the steel mill is for the purpose of machine cooling, product cooling and scale removal and transportation. The actual water application will vary widely and will depend on the type of production facility such as primary rolling, secondary rolling or continuous casting. In general, non-contact cooling water ranges from 700 to 5800 gallons per ton produced while contact water can range from 300 to 16,500 gallons per ton of production. Water of good quality is utilized in cold reduction mills. This water is either used directly or mixed with rolling oils or detergents before application. Water requirements can vary from less than 25 gallons per ton of production to over 720 gallons per ton of production.

Cold finishing operations require water to make up finishing solutions and for rinsing operations. The volumes of water required range from 50 to 500 gallons per ton of production.

Water is also required for ancillary and service facilities throughout the steel plant. This includes power production, steam generation, oxygen plants, material storage, sanitary facilities and other uses. The volumes of water required vary greatly and depend on the equipment installed, the geographical location and the required services.

IV. WATER REUSE AT STEEL MILLS

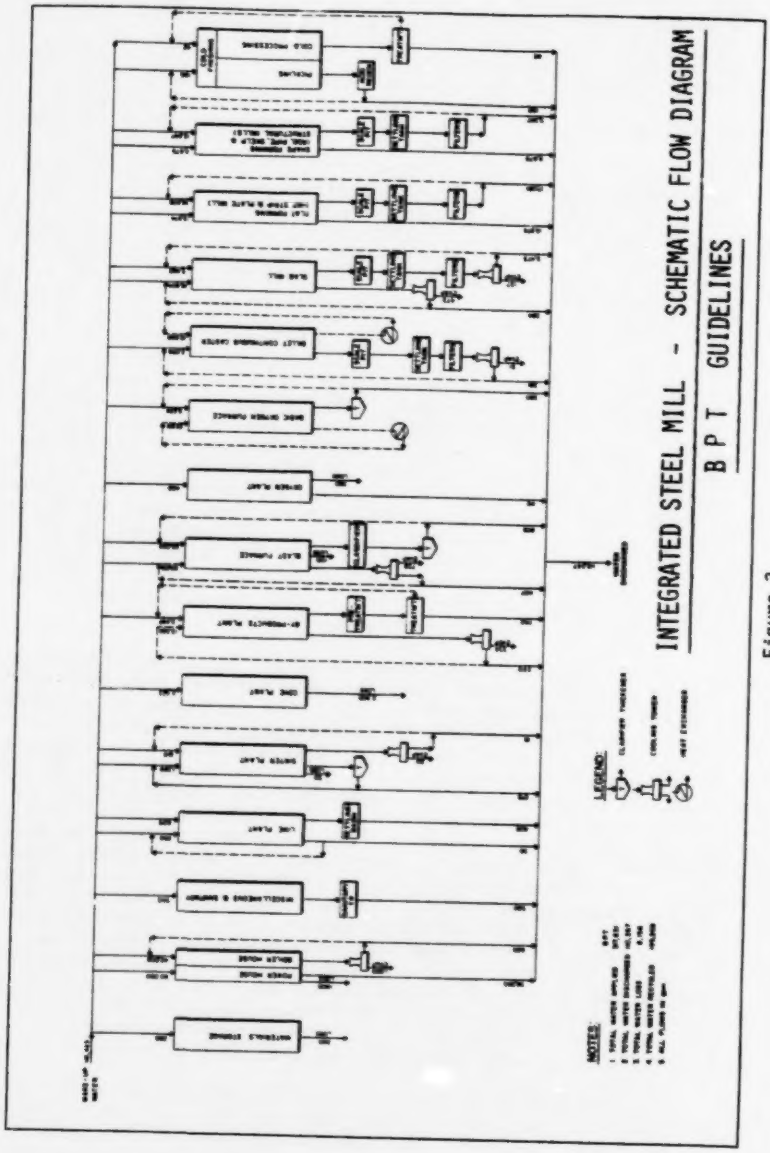
Most U.S. plants are decades old and their facilities were not designed specifically for water reuse. Basic designs, economics and space limitations are some of the factors inhibiting good retrofit installations for reuse. This situation can be and has been avoided in the case of new plants for which water reuse and recycle is a prime design criterion. Several plants exist which exhibit noteworthy water reuse primarily because they are located in water short areas.

The general situation is one in which (1) certain levels of water treatment are required by virtue of environmental legislation, (2) there is an associated degree of water reuse within the plant to achieve economical end-of-pipe treatment to comply with this legislation, (3) further incentives for water reuse may exist by virtue of the cost of treating raw water of poor quality, (4) imperatives may exist because of water scarcity, and (5) site specific opportunities for water reuse may exist among water using/discharging plants which are in reasonably close proximity.

One of the major incentives to the reuse of water is the meeting of the effluent quality as regulated by the various federal and local Governmental agencies. The major regulations which are applicable to industries throughout the United States are the United States Environmental Protection Agency's Effluent Limitations Guidelines. These guidelines are established for industries in three phases. The first phase, which was to be in effect by July 1978, is designated as Best Practicable Control Technology Currently Available (BPT). The intermediate phase, which is to be installed by 1984, is designated as Best Applicable Technology Economically Achievable (BAT). The ultimate goal of the law establishing the guidelines is the zero discharge of pollutants by 1985. The actual definition of "zero discharge of pollutants" has not been set forth and, for the purpose of this study, it has been defined as the discharge of masses of constituents no greater than those contained in the plant intake water, and at concentrations no greater than those in the receiving waters. It should be noted that the guidelines are presently under review and the assumptions made in this paper may require revision when the revised guidelines are promulgated.

To estimate the usage of water in integrated steel plants at the present time, it was assumed that BPT guidelines are being met and the necessary systems to treat the water are installed at all integrated steel plants. It should also be noted that the flow and qualities suggested in the guidelines equate to a given allowable mass discharge based on production. To determine the volumes of water required for steel production, the model 4 million ton plant was utilized. A schematic flow diagram showing the water systems: water applied, water recirculated, water evaporated and water discharged, is presented on Fig. 3. Based on the flows shown on Fig. 3 and the production for 1978, an estimate of present water usage at integrated steel plants in the United States was prepared and is presented on Table 3. The applied water necessary for making steel in the United States is estimated at 12.5 million gallons per minute. About two-thirds of this volume is supplied under BPT guidelines from the recycling or reuse systems installed that are necessary to meet BPT standards.

A model plant water system necessary to meet the BAT limits is presented schematically on Fig. 4. This figure illustrates the water applied, recirculated, evaporated, and discharged under BAT conditions and provides for recirculation within the individual production facilities to meet the BAT strictures.


MAKE-UP WATER
MATERIALS STORAGE
POWER HOUSE
BOILER HOUSE
MISCELLANEOUS & SANITARY
LIME PLANT
SINTER PLANT
COKE PLANT
BY-PRODUCTS PLANT
BLAST FURNACE
OXYGEN PLANT
BASIC OXYGEN FURNACE
BILLET CONTINUOUS CASTER
SLAB MILL
FLAT FORMING (HOT STRIP & PLATE MILL)
SHAPE FORMING (ROD, PIPE, SKELP & STRUCTURAL MILLS)
COLD FORMING
PICKLING
COLD PROCESSING
NOTES:
LEGEND:
CLARIFIER THICKENER
COOLING TOWER
HEAT EXCHANGER

INTEGRATED STEEL MILL - SCHEMATIC FLOW DIAGRAM

BPT GUIDELINES

Figure 3

TABLE 3

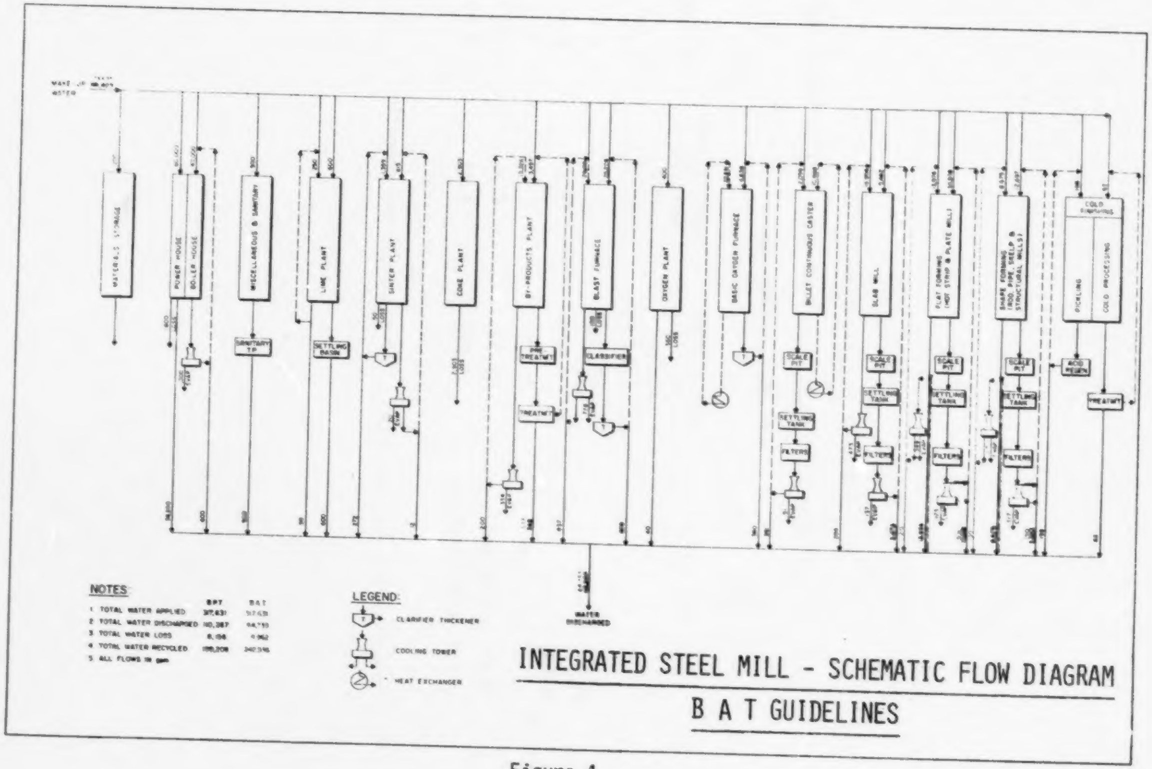
INTEGRATED STEEL PLANT WATER USAGE

BASED ON 1977 ANNUAL PRODUCTION RATE OF 155.7 MILLION INGOT TONS

BPT LEVEL TECHNOLOGY

	Application Rate (gpm per million tons)	Total Water Quantity (gpm) ($x\ 10^6$)	Gallons per Year* ($x\ 10^{12}$)
Water Applied	79,000	12.30	5.49
Water Loss	2,000	0.31	0.14
Water Recycled	50,000	7.78	3.47
Water Discharged	28,000	4.36	1.95
Fresh Water Required	30,000	4.67	2.08

*Based on 310 days per year of 24 hours per day operation.


MAKE-UP WATER
MATERIALS STORAGE
POWER HOUSE
BOILER HOUSE
MISCELLANEOUS & SANITARY
SANITARY T.P.
LIME PLANT
SETTLING BASIN
SINTER PLANT
COKE PLANT
BY-PRODUCTS PLANT
PRE TREATM'T
TREATM'T
BLAST FURNACE
CLASSIFIER
OXYGEN PLANT
BASIC OXYGEN FURNACE
BILLET CONTINUOUS CASTER
SLAB MILL
FLAT FORMING (HOT STRIP & PLATE MILL)
SHAPE FORMING (ROD, PIPE, SKELP & STRUCTURAL MILLS)
SCALE PIT
SETTLING TANK
FILTERS
PICKLING
COLD PROCESSING
COLD REDUCING
ACID REGEN
TREATM'T
LOSS
WATER DISCHARGED
NOTES:
BPT
BAT
1 TOTAL WATER APPLIED
2 TOTAL WATER DISCHARGED
3 TOTAL WATER LOSS
4 TOTAL WATER RECYCLED
5 ALL FLOWS in gpm
LEGEND:
CLARIFIER THICKENER
COOLING TOWER
HEAT EXCHANGER

INTEGRATED STEEL MILL - SCHEMATIC FLOW DIAGRAM

B A T GUIDELINES

Figure 4

This model plant of 4 million tons was also utilized to show the water applied, recirculated and evaporated to achieve the zero discharge of pollutants standard as defined in this paper. These water quantities along with the required systems are presented on Fig. 5.

The data presented on Figure 3 for BPT, Figure 4 for BAT, and Figure 5 for Zero Discharge, along with the estimated production of steel in the United States for the years 1985 and 2000 were used to predict the volume of water needed for steel production in those years, depending on the level of treatment required. The flow volumes for 1985 and 2000 are presented on Tables 4 and 5, respectively. The volumes may vary depending upon water reuse points.

As can be seen, the total water applied per million tons of production is the same regardless of which guideline is used. However, as limitations become more stringent, the rate of water discharged falls and the rate of water lost rises as more water is forced back into the system for reuse.

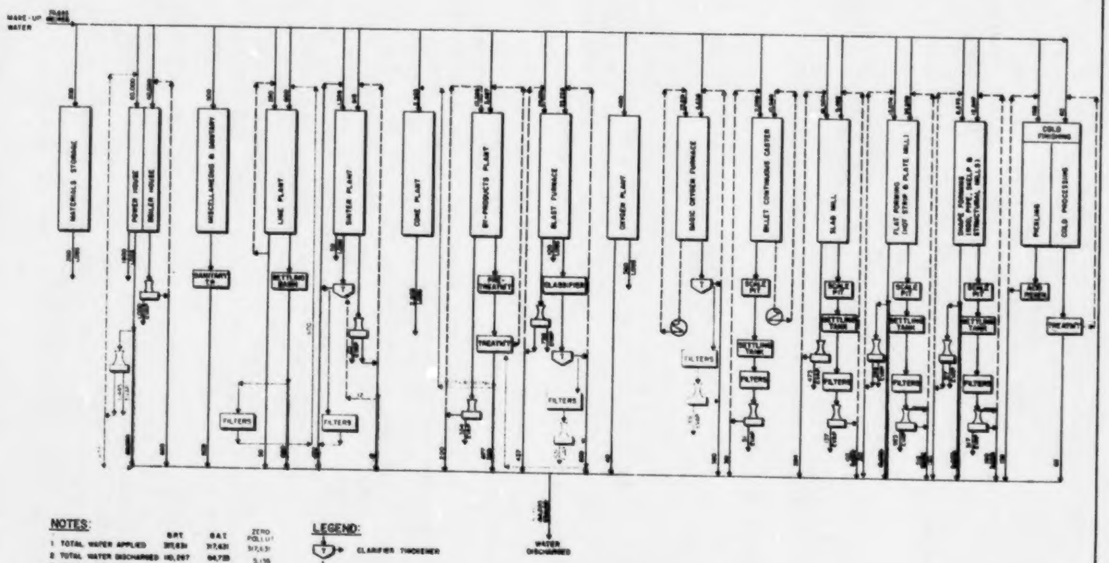
Internal Water Reuse Systems

The internal water reuse systems in the steel industry take two basic forms. The first, which is the recycle of water within the same production facility area, is the approach taken at many facilities for the various levels of treatment under BPT, BAT and zero pollution previously indicated. The second method is the reuse of water from one production facility at another production facility requiring a lower quality water.

This second approach, which is also referred to as the cascading of water, can be applied at various locations throughout one steel plant. The factors governing reuse are: the quality of the water that is discharged from one process, the water quality required for application at the process which will utilize the water and also the relative locations of the discharging process and the user process. The possibility of using production contact water which normally becomes contaminated by the product should be evaluated at each installation and for each reuse application. In general, water that can be cascaded, based on water quality, is water used for non-contact cooling. This water, before cooling, or that discharged as blowdown from the cooling towers, can be cascaded and reused as contact water at various plant production facilities.

Applying the same approach to the system shown on Figure 4 for BAT Guidelines, the additional volume of water recoverable for reuse for the previously indicated production facilities is approximately 1960 gpm. The volume is reduced due to the fact that flat forming and shape forming operations would already be on recirculating systems and only the cooling tower blowdown is available for cascading.

When considering the recovery of non-contact cooling water under the zero pollution guidelines, Figure 5, the additional volume of water recoverable for cascading is approximately 1950 gpm.


MAKE-UP WATER
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MISCELLANEOUS & SANITARY
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BLAST FURNACE
OXYGEN PLANT
BASIC OXYGEN FURNACE
BILLET CONTINUOUS CASTER
SLAB MILL
FLAT FORMING (HOT STRIP & PLATE MILL)
SHAPE FORMING (ROD, PIPE, SKELP & STRUCTURAL MILLS)
COLD FINISHING
PICKLING
COLD PROCESSING
SANITARY TP
SETTLING BASIN
FILTERS
PRE-TREATMT
TREATMT
CLASSIFIER
SCALE PIT
SETTLING TANK
ACID REGEN
WATER DISCHARGED

NOTES:

	B.P.T	B.A.T	ZERO POLLUT
1 TOTAL WATER APPLIED	317,631	317,631	317,631
2 TOTAL WATER DISCHARGED	110,267	64,723	5,136
3 TOTAL WATER LOSS	8,156	9,860	11,203
4 TOTAL WATER RECYCLED	199,208	242,868	301,292

5 ALL FLOWS in gpm

LEGEND:

CLARIFIER THICKENER

COOLING TOWER

HEAT EXCHANGER

INTEGRATED STEEL MILL - SCHEMATIC FLOW DIAGRAM

ZERO POLLUTION

Figure 5

TABLE 4

INTEGRATED STEEL PLANT WATER USAGE
BASED ON PROJECTED 1985 PRODUCTION RATE OF
170 MILLION INGOT TONS

	Rate	Total Water Quantity	
	gpm/ton x 10^6	gpm(x 10^6)	gal/yr* (x 10^{12})
	BPT TECHNOLOGY		
Water Applied	79,000	13.43	5.99
Water Loss	2,000	0.34	0.15
Water Recycled	50,000	8.50	3.79
Water Discharged	27,000	4.59	2.12
Fresh Water Required	29,000	4.93	2.27
	BAT TECHNOLOGY		
Water Applied	79,000	13.43	5.99
Water Loss	2,500	0.43	0.19
Water Recycled	61,000	10.37	4.63
Water Discharged	15,500	2.64	1.21
Fresh Water Required	18,000	3.06	1.41
	ZERO POLLUTION TECHNOLOGY		
Water Applied	79,000	13.43	5.99
Water Loss	2,800	0.48	0.21
Water Recycled	75,000	12.75	5.69
Water Discharged	1,200	0.20	0.10
Fresh Water Required	4,000	0.68	0.30

*Based on 310 days per year of 24 hours per day operation.

TABLE 5

INTEGRATED STEEL PLANT WATER USAGE BASED ON PROJECTED 2000 PRODUCTION RATE OF 190 MILLION INGOT TONS

	Rate	Total Water Quantity	
	gpm/ton x 10^6	gpm (x 10^6)	gal/yr* (x 10^{12})
	BPT TECHNOLOGY		
Water Applied	79,000	15.01	6.70
Water Loss	2,000	0.38	0.17
Water Recycled	50,000	9.50	4.24
Water Discharged	27,000	5.12	2.37
Fresh Water Required	29,000	5.51	2.54
	BAT TECHNOLOGY		
Water Applied	79,000	15.01	6.70
Water Loss	2,500	0.475	0.21
Water Recycled	61,000	11.59	5.17
Water Discharged	15,500	2.95	1.36
Fresh Water Required	18,000	3.42	1.57
	ZERO POLLUTION TECHNOLOGY		
Water Applied	79,000	15.01	6.70
Water Loss	2,800	0.532	0.24
Water Recycled	75,000	14.25	6.36
Water Discharged	1,200	0.25	0.10
Fresh Water Required	4,000	0.76	0.34

*Based on 310 days per year of 24 hours per day operation.

Possibilities for In-Plant Reuse

There are many possibilities for the recycle and reuse of water within the hypothesized steel plant. The quality of water required at types of facilities for specific uses shown on Table 1 was compared to the qualities that would be discharged under BPT and BAT requirements. Using these comparisons, it was determined that there are fewer areas of reuse attainable by treating the water to BAT levels over BPT levels. The primary reason for this is that the additional limitations imposed by BAT level treatment over BPT level are due to limitations of parameters that are of no concern with reuse but are of concern for discharge to receiving bodies of water. It should also be noted that in areas where lower blowdowns are indicated, the dissolved solids are increased due to the increase in cycles of concentration, thereby rendering the water unfit for reuse.

The water discharged under the zero discharge of pollutants will be of a quality to be reused at every point in the steel plant since the water, by definition of zero discharge of pollutants, will contain concentrations no greater than those in the receiving waters.

The concept of reuse should be used with caution. Reuse is dependent to a great degree on the physical location of facilities within the integrated steel plant. For example, it would be unlikely that cooling tower blowdown at a coke plant or blast furnace would be available for product contact water makeup at shape rolling facilities since at virtually all steel plants where these operations are present, they are not near each other, and to bring the water from the point of discharge to the point of reuse would neither be convenient nor economical.

External Sources of Water Supply

Water used by others outside a steel plant can be considered by a steel plant for reuse as process or industrial water supply. The quality of water discharged by the first user must be compatible with the quality of water required for the products being made or production facilities operating at the steel plant. In addition to the quality of water discharged by the first user, it is necessary to insure that the water supply is thoroughly dependable, therefore, additional storage capacity at a steel plant might be considered to handle flow fluctuations from the external sources. Some of the external water sources which are possible for reuse are treated municipal waste waters, cooling waters from nearby power generating plants and other industrial effluents which are not overly contaminated with dissolved or suspended materials that might be harmful to steel plant processes or products.

However, when utilizing wastes from another manufacturing plant, a utility or a municipal treatment plant external to the plant as a source of water for a steel plant, it must be established that the external sources are meeting the requirements for BPT, BAT or zero discharge of pollutants as defined. This is necessary so that no undue burden is placed upon the steel plant with respect to waste treatment. If the waters from external sources do not meet effluent requirements established for those sources, but are of a quality suitable for steel plant use, then it might be advisable and mutually advantageous to have the water supplier share the costs of waste treatment so that the discharge from the steel plant would meet the cumulative criteria for both, or any number of combined waste water discharges.

V. TECHNOLOGY ASSESSMENT

General

The BAT guidelines issued by the U.S. EPA for steel plants have been issued as preliminary discussion guidelines. For the purpose of this discussion, the mass allowable discharges were hypothesized on the basis of production for the most probable value for the quantity of water discharged for a "tight system." Once the volume to be discharged was established, the level of treatment attainable was determined, based on literature available, and actual results of treatment observed. The mass discharge "allowables" were established based on the qualities theoretically attainable, those being achieved on a concentration basis, and also on the volume of discharges allowable. Non-contact cooling water was considered as being excluded from all treatment systems.

Table 6 identifies the treatment methods suggested in the proposed guidelines for the regulated parameters at each of the production facilities considered. The table presents the treatment which is proposed in addition to that which is normally present at facilities to meet BPT technology and those which must be added to BPT to meet BAT limitations.

E.P.A. regulations are intended to maintain or enhance stream quality, and the parameters which are regulated serve this end. In this paper, however, unregulated parameters which may affect product quality and do not impact on the environment are also considered. Examples include chlorides or other dissolved solids discharged from plating rinses.

Present (BPT) Technology

The technologies proposed in the development documents for the control of the various parameters repeat at many of the production facilities considered. Since the parameters are regulated on the basis of "most probable value for tight system(s)" and the allowable mass discharge of each parameter, recycling of waste water either prior to or subsequent to treatment must be considered as a waste water control technology. The recycled water may or may not require cooling.

TABLE 6

WASTE TREATMENT TECHNOLOGIES[a]

1. Adsorption
2. Ammonia Stripping - Free Leg
3. Ammonia Stripping - Fixed Leg
4. Ammonia Absorption
5. Biological Oxidation (one stage)
6. Biological Oxidation (multi-stage)
7. Chemical Oxidation (incl. cyanide)
8. Chemical Reduction (incl. chromium conversion)
9. Chlorination (alkaline)
10. Deep Well
11. Distillation
12. Emulsion Breaking
13. Filtration: Carbon
14. Filtration: Deep Bed (sand)
15. Filtration: Flat Bed
16. Filtration: Pressure
17. Filtration: Other (identify)
18. Flocculation (coagulation) with Lime
19. Flocculation (coagulation) with Alum
20. Flocculation (coagulation) with Polymer
21. Flocculation (coagulation) with Acid
22. Flotation
23. Ion Exchange
24. Neutralization with Lime
25. Neutralization with Caustic
26. Neutralization using Wastes from other Sources
27. Neutralization with Acid
28. Neutralization with Other Chemicals
29. Reverse Osmosis
30. Screening
31. Sedimentation with Clarifiers
32. Sedimentation with Lagoons
33. Sedimentation with Primary Scale Pit
34. Sedimentation with Secondary Scale Pit
35. Sedimentation with Thickeners
36. Skimming
37. Recycle with cooling
38. Recycle without cooling
39. Aeration

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[a] The treatment technologies shown in this list are identical to the technologies steel plants used as references in preparing their responses to the survey of the industry referred to in Chapter 2 of this report.

BAT Technology

The technologies for the meeting of BAT guidelines, in most cases, are not very much different from those for the meeting of BPT guidelines. The primary differences or additions occur in the area of the removal of ammonia, where multi-stage biological treatment is a proposed method of treatment.

The treatment systems achieve the mass limitations in some cases by requiring additional recirculation of water after it is treated and discharging smaller quantities of treated water.

Zero Pollution

As defined earlier in this presentation, zero pollution is the discharge of water that contains mass loads no greater than those drawn into the plant and at concentrations no greater than exist in the receiving waters. To reach this goal, more sophisticated methods of removal are required. If the intake water contains none of a given constituent, say zinc, then none is permitted to be discharged. In that instance the definition of zero pollution may become synonymous with zero discharge of water since, in the removal of the zinc ion, it may be necessary to completely demineralize the water for discharge unless a removal method specific for zinc is avaliable.

Under the definition for zero discharge of pollutants, the maximum recirculation of non-contact cooling water may not be the most practical means to be followed. In recirculating cooling water it is necessary, in most cases, to add chemicals for corrosion and scaling inhibition and to act as biocides. These chemicals would add to the mass loadings due to the blowdown required to maintain the dissolved solids levels in the recirculation systems. It may therefore be necessary to demineralize non-contact cooling water system blowdowns unless the intake water is of such a quality that no chemical additions are required.

In some cases, steel plants are disposing of contaminated water by quenching of incandescent coke and molten slag. However, indications from the EPA are that water with high dissolved solids concentrations may not be permitted to be used for these purposes in the future. Research conducted by the EPA and contracting organizations has indicated that particulate air pollution is greatly increased when water with high dissolved solids is used for these purposes.

The ultimate treatment, as stated above, is the demineralization of portions of the waste streams to meet the mass discharge criteria. To achieve those mass loadings, the plant or individual plant processes must meet the basic criterion that there will be no net addition of regulated constituents in the waste stream as a result of the production processes. In addition, consideration must be given to both the source of the water taken into the plant and the receiving body that the plant discharges to and both of their background qualities.

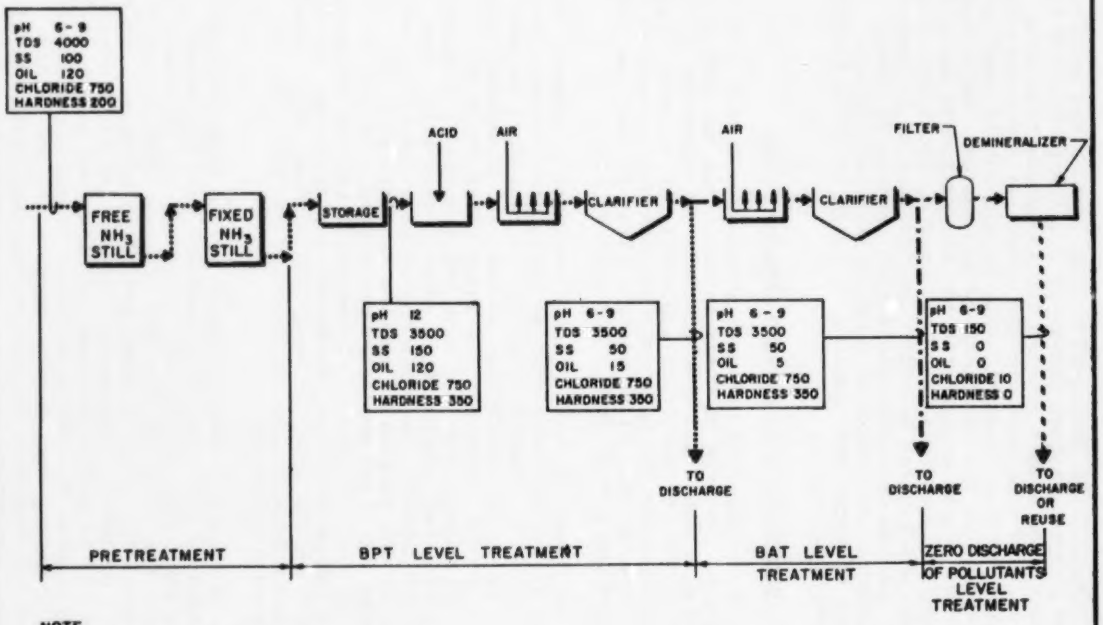
Each of the demineralization methods has been proven in some process, either treatment for the production of pure water, as a unit process for the production of a product or as a process for the treatment for a specific industrial waste. However, they should not be used indiscriminately for the treatment of all wastes. Each process considered should be specific to the individual waste or the combinations of wastes considered to determine which is the most applicable, or which combinations of processes and wastes are the most compatible with respect to energy requirements, materials of construction, efficiency, recovery of water and possible recovery of waste materials for commercial value.

Use of Technologies to Achieve Desired Goals

Utilizing some of the technologies listed in Table 6, examples of the uses of these technologies are presented in Figures 6, 7 and 8 and show the "add on" character of the treatment and the qualities achievable after each stage. The figures show the treatment which might be applied to the by-product coke plant wastes, blast furnace gas cleaning water and the wastes from a hot rolling mill.

In Figure 6, coke plant by-product treatment, the ammonia stills are indicated as being pre-treatment whereby the quantity of ammonia, a guideline regulated parameter, is reduced prior to treatment. To meet BPT standards, single stage biological treatment is shown after which the treated wastes are discharged. To meet BAT standards, a second stage biological treatment is added. This stage does nothing to improve the reuse characteristics of the waste but is for the purpose of meeting the more stringent standards for other regulated parameters. To achieve zero pollution the BAT treated wastes would require demineralization to reduce the total dissolved solids to the level of the plant intake water or receiving stream. This treated water would be suitable for reuse at any point in the integrated steel plant.

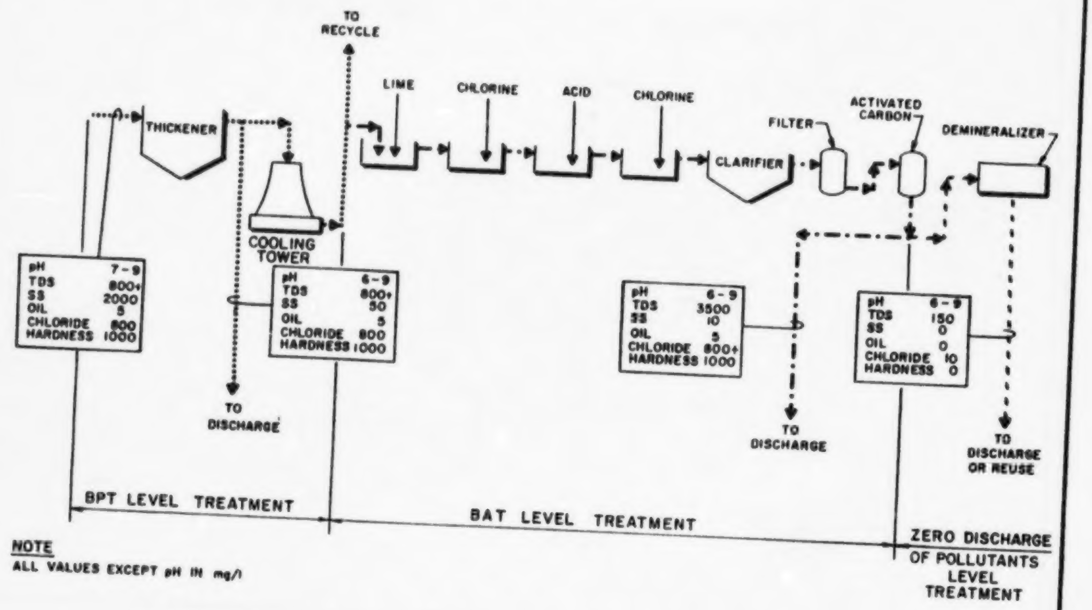
In Figure 7, BAT treatment at the blast furnace, when added to BPT treatment, does not make the water treated any more suitable for reuse but the treatment serves to permit the plant to meet the effluent limitations established for blast furnace gas cleaning water. To meet the zero pollution requirement, demineralization would also be required to reduce the mass of dissolved solids that have been added due to the solution of gas constituents in the water during the cleaning process and due to the addition of chemicals during the treatment for removal of regulated parameters.


pH 6-9
TDS 4000
SS 100
OIL 120
CHLORIDE 750
HARDNESS 200
FREE NH3 STILL
FIXED NH3 STILL
STORAGE
ACID
AIR
CLARIFIER
AIR
CLARIFIER
FILTER
DEMINERALIZER
pH 12
TDS 3500
SS 150
OIL 120
CHLORIDE 750
HARDNESS 350
pH 6-9
TDS 3500
SS 50
OIL 15
CHLORIDE 750
HARDNESS 350
pH 6-9
TDS 3500
SS 50
OIL 5
CHLORIDE 750
HARDNESS 350
pH 6-9
TDS 150
SS 0
OIL 0
CHLORIDE 10
HARDNESS 0
TO DISCHARGE
TO DISCHARGE
TO DISCHARGE OR REUSE
PRETREATMENT
BPT LEVEL TREATMENT
BAT LEVEL TREATMENT
ZERO DISCHARGE OF POLLUTANTS LEVEL TREATMENT

NOTE
ALL VALUES EXCEPT pH IN mg/l

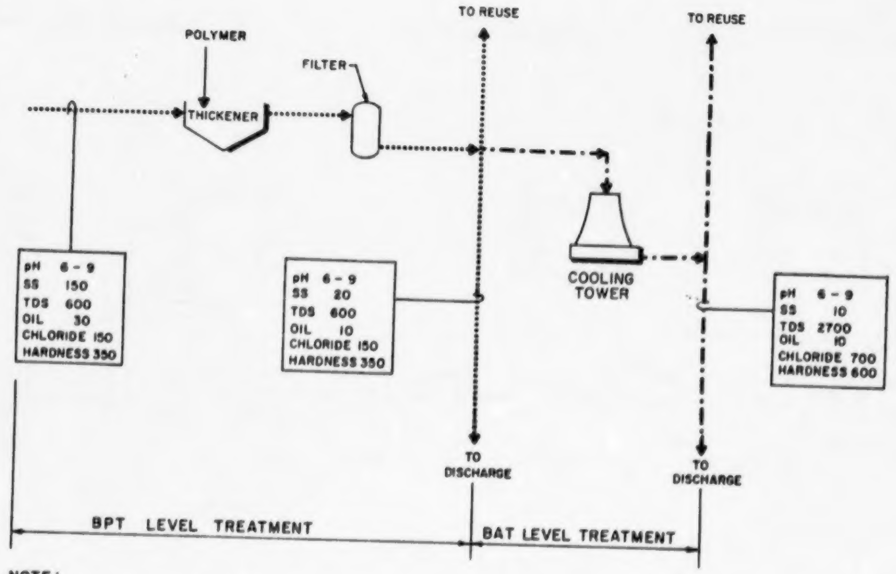
COKE BY-PRODUCT PLANT WASTE TREATMENT

Figure 6


TO RECYCLE
LIME
CHLORINE
ACID
CHLORINE
THICKENER
COOLING TOWER
CLARIFIER
FILTER
ACTIVATED CARBON
DEMINERALIZER
pH 7-9
TDS 800+
SS 2000
OIL 5
CHLORIDE 800
HARDNESS 1000
pH 6-9
TDS 800+
SS 50
OIL 5
CHLORIDE 800
HARDNESS 1000
pH 6-9
TDS 3500
SS 10
OIL 5
CHLORIDE 800+
HARDNESS 1000
pH 6-9
TDS 150
SS 0
OIL 0
CHLORIDE 10
HARDNESS 0
TO DISCHARGE
TO DISCHARGE
TO DISCHARGE OR REUSE
BPT LEVEL TREATMENT
BAT LEVEL TREATMENT
ZERO DISCHARGE OF POLLUTANTS LEVEL TREATMENT
NOTE
ALL VALUES EXCEPT pH IN mg/l

BLAST FURNACE GAS WASHER WATER TREATMENT

Figure 7


POLYMER
THICKENER
FILTER
TO REUSE
TO REUSE
COOLING TOWER
TO DISCHARGE
TO DISCHARGE
pH 6 - 9
SS 150
TDS 600
OIL 30
CHLORIDE 150
HARDNESS 350
pH 6 - 9
SS 20
TDS 600
OIL 10
CHLORIDE 150
HARDNESS 350
pH 6 - 9
SS 10
TDS 2700
OIL 10
CHLORIDE 700
HARDNESS 600
BPT LEVEL TREATMENT
BAT LEVEL TREATMENT

NOTE:
ALL VALUES EXCEPT pH IN mg/l

HOT MILLS WASTEWATER TREATMENT

Figure 8

Figure 8 shows the treatment required for a hot rolling mill to meet both BPT and BAT. The basic difference is that recirculation within the mill is increased to achieve a lower volume of discharge. However, in so doing, the water that is ultimately discharged is not suitable for reuse at as many areas. In this scheme both the concept of increased reuse and reduced pollutant discharge are both achieved.

The three treatment flow diagrams presented do not address the ultimate disposal of concentrated residual waste streams that will remain after demineralization to meet zero pollution levels, or to the disposal of solids both soluble and insoluble that may be removed from the wastes being treated.

VI. CONSIDERATION FOR MAXIMUM REUSE OF WATER AND NEED FOR FURTHER RESEARCH AND DEVELOPMENT

As described previously, water scarcity implies a reliable supply to demand ratio of less than unity when there are competing users exerting a demand. Within an integrated steel plant, water scarcity is not usually a problem when the plant initially is constructed. It may become a problem when plans for expansion are being made. Then, detailed studies are usually made whereby internal distribution systems are analyzed, external water sources that can provide a fully reliable supply are sought, internal reuse and recycle systems are considered and water quality requirements at various facilities are re-evaluated.

Since all users require both a source of water and a means to discharge water, they would all by individual preference be located adjacent to a river or a lake. However, the river or lake must serve a multiplicity of purposes when there are many municipal-industrial complexes both upstream and downstream. The riparian rights of all must be preserved. Therefore, the net abstraction of water from the river by the industries must be minimized while still preserving river water quality to protect public health. It is at this point that a dichotomy of purposes is reached. As can be seen for the discussion of steel plant water usage, as the degree of treatment increases the water losses also increase.

The question that arises therefore is, "In the extreme case, is no water preferable to water of degraded quality?" No water is clearly not acceptable but under the zero discharge criterion, it is possible that, using currently available technology, the only water permissible for discharge may be the equivalent of demineralized water. No aquatic flora or fauna can exist in this situation due to lack of nutrients. The environmental objectives sought by "cleaning up" the waterways in strict compliance with regulatory constraints would not be met.

It would be advisable therefore not to discharge the demineralized water into the stream but to recirculate it within the plant or complex and treat it only to such a degree whereby it resembles but does not necessarily equal the river water quality. Thus, conditions of zero discharge of water have been created rather than the zero discharge of pollutants. As was shown previously, as the degree of treatment increases, the net water loss also increases. Under these conditions there will be an increase in the consumptive use of water at a complex or individual plant. This may contribute to the existence or possibility of water scarcity downstream.

Need for Research and Development

Further research and development into non-chemical means of pollution control is necessary if the goal of zero pollution is to be reached while minimizing loss of water. Chemical treatment, by its very nature, almost always introduces a greater quantity of chemicals into the effluent stream than is being removed. However, as has been pointed out earlier, the more treatment applied, the greater the water losses. Water losses and costs increase as the energy applied is increased. It is therefore necessary that methods be developed or optimized for the treatment of waste water that consumes a minimum amount of energy without any sacrifice in quality of effluent. In addition, it is desirable that methods be developed for the removal of specific contaminants or pollutants. If only the added materials could be removed while leaving the water as drawn into the system intact, then less water would be lost and solids disposal problems would be minimized. The most probable method would be some membrane technology, such as electrodialysis or ultrafiltration.

In addition to physical means of treatment, biological means require development where biodegradable contaminants are present. In steel plants this development is particularly needed especially at coke plants and blast furnaces where metabolic action, if not carried to its ultimate, does result in discharge of materials that would not meet zero pollution criteria under any definition.

After ultimate treatment there is always a residue, be it a concentrated aqueous waste or solids, that must be disposed of. Therefore, as an integral part of creating from a waste water a water that has a quality that is adequate for reuse, due consideration must be given to disposal of wastes removed. The method of final disposal must be in a manner such that all environmental constraints are met including, but not limited to, ensurance for the prevention of reentry of the wastes into any water system.

PB82-223553

ALUMINUM MILL WASTEWATER REUSE
USING DEMINERALIZATION TECHNIQUES

Richard Osantowski, Project Engineer
Anthony Geinopolos, Assistant Director
Rexnord, Inc.
EnviroEnergy Technology Center (EETC)
Milwaukee, Wisconsin 53214

INTRODUCTION

An indepth pilot scale investigation was conducted to determine the feasibility of treating primary aluminum mill wastewater to a quality acceptable for non-potable reuse. Two demineralization technologies were studied, namely, reverse osmosis and electrodialysis. Pretreatment consisted of chemical clarification and multimedia filtration. This paper describes in brief the equipment used in the study and presents a summary of the research findings. The project was funded by the U.S. Department of Interior, Office of Water Research and Technology under contract no. 14-34-0001-7805.

Project Background

In the United States, there are 12 companies operating 32 plants engaged in primary aluminum production. In 1978, 4,804,000 tons (4,357,000 metric tons) of aluminum were produced. The aluminum subcategory is a high water usage industry as indicated by annual gross water usage. For example, yearly usage is estimated at 722 billion gallons (2.732×10^{11} liters) with 173 billion gallons (6.55×10^{10} liters) being discharged. The specific site investigated produces 450,000 tons (408,150 metric tons) of finished product per year and is a major supplier of aluminum to the can industry. Wastewater flow typically averages 4 mgd (15,140 m^3/day).

The advanced waste treatment trains investigated on a pilot basis included the following:

1. CF + F + RO
2. CF + F + ED

Key
CF = chemical flocculation/clarification
F = multimedia filtration
RO = reverse osmosis
ED = electrodialysis

In the first pilot treatment train, the aluminum plant effluent (Best Practical Control Technology Currently Available effluent) was chemically treated and clarified, filtered, pH adjusted and demineralized using reverse osmosis. The second treatment train again consisted of chemical clarification and filtration. The wastewater was then desalted using electrodialysis.

Membrane life testing was performed as a part of the study. During the investigation, more than 3,000 hours of operating time was put on the reverse osmosis and electrodialysis membranes. The treatment train arrangements studied during this project are shown in Figure 1. Typical feedwater flow to the pilot units was 15 gallons per minute (57 liters/min).

Pilot System Description

The investigation was conducted using the Office of Water Research and Technology's (OWRT's) mobile desalting treatment system in conjunction with the Rexnord Advanced Waste Treatment vehicle. These pilot plants are housed in two semi-trailer vans as shown in Figures 2 and 3.

The OWRT reverse osmosis (RO) unit consisted of a pressure vessel housing three polyamide spiral wound membranes. The unit operated at feed pressures of 300 to 400 psi (21 to 28 kg/cm^2). The system was equipped with a brine recycle loop to achieve 75 percent product water recovery. Protection for the system was provided by high and low pressure switches and an in-line cartridge filter (10 μ). The electrodialysis (ED) unit contained four hydraulic stages and two electrical stages. The arrangement was such that two hydraulic stages occurred within each electrical stage. The cell pair arrangement per hydraulic stage was 25 and 18 with a total of 86 cation-anion cell pairs. The pilot unit was equipped with the capability to recycle brine and achieve a product recovery of 85 percent. The system also was equipped with a timer operated polarity reversal to continually flush the electrodes during operation.

Major components of the Rexnord Advanced Waste Treatment (AWT) Van included flocculation/clarification and multimedia pressure filtration. An extensive system of pressure and flow gauges, pH, flow control and filter backwash are contained in the AWT trailer. The clarification system consisted of a 2,000 gallon (7,570 liter) flocculator/clarifier with a net surface area for clarification of 43.4 ft^2 (4.0 m^2). Chemical addition is accomplished with a five pump system. The pressure multimedia filter was a 20 inch (50.8 cm) diameter unit equipped with an automatic backwash system including adjustable air scour. Filtration media used in the test program consisted of 3 inches (7.6 cm) of garnet sand, 9 inches (22.9 cm) of silica sand, 18 inches (45.7 cm) of anthracite coal.

During the pilot study, samples were collected daily for conventional pollutants. Operational data were also recorded daily to evaluate the effectiveness of the respective treatment trains. Pilot study results were evaluated using the criteria listed below:

1. Process and/or treatment train performance.
2. Brine or residual disposal.

The mobile pilot treatment systems were on site at the aluminum products plant from October, 1979 to April, 1980. Both the demineralization and pretreatment technologies were operated continuously throughout the study, except for routine maintenance and regularly scheduled cleaning.

EXPERIMENTAL TEST RESULTS

The advanced waste treatment processes were evaluated on the basis of pilot system performance. The results of the pilot program demonstrated that both pilot treatment trains investigated were effective in reducing influent aluminum plant wastewater contaminants to below non-potable water quality limitations.

Effluent Pretreatment

Chemical flocculation/clarification and multimedia filtration were effective in reducing the contaminant strength of the incoming wastewater to make it acceptable as feedwater to the membrane processes. A summary of pretreatment performance data is shown below in Table 1.

The data obtained during the study determined that for optimum clarification, a chemical dosage of 50 mg/l ferric chloride and 0.2 mg/l polyelectrolyte would be required. The performance data indicated that the pilot scale clarifier was capable of reducing the influent suspended solids by 35 percent and turbidity by 62 percent. The sludge produced comprised approximately 15 percent of the total flow. Settling tests conducted during the research program determined the average and range of settling rates to be 0.095 ft/min (0.360 m/min) and 0.082 to 0.120 ft/min (0.310 to 0.454 m/min), respectively. The full-scale clarification system was designed for an overflow rate of 392 gpd/ft^2 (16 m^3/m^2·d).

Multimedia filtration of the clarified effluent was capable of further reducing the remaining turbidity by 90 percent and suspended solids by 60 percent. Research data are shown in Table 2. Filtered effluent turbidity averaged 0.60 NTU and provided a good quality feed to the demineralization process. The average Millipore Pluggage Index of the filter effluent during the study was 8.1. Media headloss profiles taken during the filter runs indicated the presence of in-depth filtration. The data indicated that the majority of solids capture occurred in the garnet and silica sand layers rather than in the anthracite coal layer. Direct filtration of chemically pretreated water proved unsatisfactory due to poor effluent quality. A pressure filtration system operating at a filtration rate of 4 gpm/ft^2 (163 lpm/m^2) was selected as optimum based on the pilot study data. A filtration cycle time of 13.1 hours was projected for the full-scale system.

Wastewater Demineralization

The wastewater demineralization testing program goal was to put a minimum of 3000 operating hours on each pilot technology. This goal was established to provide long term operating data that could be used to predict membrane life for the water reuse application. The study determined that each of the demineralization processes evaluated during the pilot study was capable of producing a high quality effluent. In fact, the product water qualities of the two membrane processes were quite similar and were of significantly higher quality than the current plant well water supply. Each membrane technology was capable of removing in excess of 90 percent of the feedwater total dissolved solids from the aluminum plant effluent. Additional discussion on each of the desalting technology results is presented below.

Reverse Osmosis. A total of 3020.1 hours were put on the reverse osmosis membranes during the test program. The pilot unit was operated at product water recoveries ranging from 65 to 75 percent for the majority of the test program. Run times under these operating conditions ranged to 183.4 hours. Examination of the operating data indicated that run times were significantly influenced by feedwater turbidity. A maximum feedwater turbidity limit of 1.0 NTU was used during the pilot study, however, the data indicated that a maximum feedwater turbidity of 0.5 NTU would be more appropriate. Based on the study data and assuming a feedwater turbidity of 0.5 NTU or less, a full-scale reverse osmosis system typically would require cleaning once every seven days.

A portion of the test program was used to evaluate system operation at at product water recovery range of 80 to 85 percent. Run times during this period were quite short. The poor run times were achieved using feedwater with average turbidities less than 0.40 NTU. The data indicated that operation in the 80 to 85 percent product recovery range was not feasible for this application.

The pilot study indicated that after an initial flux decline, no significant decline occurred over the remainder of the study. Based on the data obtained in the pilot study, a full-scale reverse osmosis system would exhibit an initial flux decline period and no further flux decline for at least the first 3000 hours of operation. The membrane life of the system would be expected to meet or exceed the 3 year performance period given by the manufacturer.

Table 3 presents a projection of the product water quality that could be expected from a full size reverse osmosis system. As can be seen in Table 3, reverse osmosis is capable of producing a high quality product water suitable for several non-potable reuse applications.

A reverse osmosis system operating at 75 percent product water recovery will produce 1 gallon (3.785 liters) of brine for every 3 gallons (11.36 liters) of product water. The brine will contain most of the contaminants present in the feed at 3 to 4 times the original concentration. The concentrations presented in Table 4 are representative of brine that would be produced in a full size system.

This can then be compared to the aluminum plant's NPDES permit limitations for their process water outfall, which is also shown in Table 4.

Comparing the permit limitations with the brine characteristics indicates that a full size RO system brine would exceed the permit limitations on pH range and fluoride concentration if discharged directly. However, sufficient quantities of non-contact cooling water and treated sanitary wastewater are available to use as dilution water prior to discharge to the receiving body.

The major reverse osmosis membrane foulants were identified as algae and a ferric iron precipitate. A full scale system could be operated at a design TDS rejection of 96 percent and 75 percent product water recovery.

Electrodialysis. A total of 3080.6 hours were put on the electrodialysis unit during the test program. The pilot unit was typically operated at product recovery ranges of 65 to 75 percent. The test program indicated that a full-scale electrodialysis system would require cleaning once every 14 days. Data collected in the pilot study indicated that no significant permanent membrane fouling occurred in the first 3000 operating hours.

Table 5 presents the product water quality that could be expected from a full size system, based on the performance of the pilot unit. Electrodialysis product water, similar in quality to RO product, would also be suitable for several non-potable reuse applications.

The brine characteristics shown in Table 6 are representative of the brine that would be produced in a full-scale electrodialysis unit. The brine contains relatively high concentrations of dissolved solids and low organics and nutrients. The low brine concentrations of organics and nutrients are due to the poor rejection of non-polarized pollutants characteristic of electrodialysis. The ED brine would exceed the aluminum plant discharge permit limitation for fluoride. Again, sufficient dilution water is available to meet the NPDES fluoride concentration limitation.

WASTEWATER REUSE POTENTIAL

The plant's current water supply is taken from a system of wells at rates ranging from 6.0 to 9.5 mgd (22,700 to 36,000 m^3/day) with an average of 7.5 mgd (28,400 m^3/day). Potable water is also taken from this well system but is not included in the flows given. Table 7 indicates the average quality of the plant water supply. A 0.864 mgd (3,255 m^3/day) deionization system is used to produce high quality water (conductivity less than 15 μmhos/cm) for use as rolling lubricant solution. A 80,000 gpd (303 m^3/day) sodium zeolite softening system produces feedwater for evaporators providing steam used in the aluminum ore smelting process.

Comparing the quality of the current plant supply to the product water quality of the demineralization processes (Tables 3 and 5), it is obvious that both product waters exceed the quality of the current supply.

All of the principal water using processes at the aluminum plant are potential candidates for wastewater reuse, provided the economics of treatment can be justified and water quality requirements met.

Table 8 presents a summary of the potential reuse applications and the degree of treatment required to satisfy water quality requirements. Product water from either a reverse osmosis or electrodialysis desalting process could be used as feedwater to the existing deionization system or as a replacement for the softened water. The use of product water as deionizer feedwater would significantly reduce the regeneration requirements of the current system. Cooling tower makeup water quality requirements could be achieved using a blend of 70 percent desalting process product water with 30 percent chemically clarified and filtered effluent. Non-contact cooling water requirements can be met by directly recycling raw process wastewater without treatment. The water quality requirements of the fabricating plant coatings waste and the inert gas scrubber water makeup would be similar to the present well water quality. A water of similar chemical makeup could be obtained by blending 75 percent chemically clarified, filtered water with 25 percent desalting process product water.

SUMMARY AND CONCLUSIONS

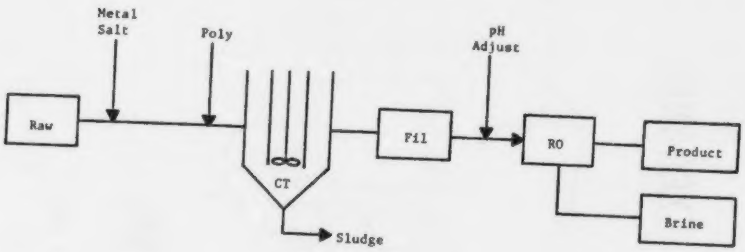
The results of the study indicated that:

1. Chemical flocculation/clarification and filtration provided sufficient pretreatment for the desalting processes.
2. Excellent rejections of dissolved solids were achieved by the reverse osmosis and electrodialysis pilot units. The reverse osmosis and electrodialysis product waters were suitable for non-potable reuse applications.
3. Several potential reuse areas were identified at the aluminum plant research site. The most promising areas include using desalting process product water as deionizer system feedwater and direct recycling of process wastewater for non-contact cooling.

Acknowledgements

The authors acknowledge the cooperation and support of the Office of Water Research and Technology, U.S. Department of Interior. The assistance given by Allen Ford, Project Officer and Robert Madancy, Office of Water Research and Technology was received with much appreciation.

(1) CHEMICAL TREATMENT/CLARIFICATION, FILTRATION, REVERSE OSMOSIS


Metal Salt
Poly
pH Adjust
Raw
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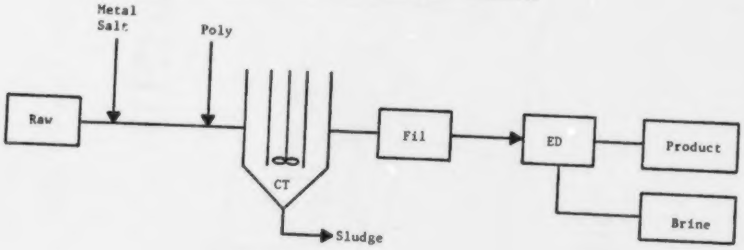
Fil
RO
Product
Brine
Sludge

(2) CHEMICAL TREATMENT/CLARIFICATION, FILTRATION, ELECTRODIALYSIS


Metal Salt
Poly
Raw
CT
Fil
ED
Product
Brine
Sludge

KEY

CT: Chemical Treatment/Clarification
FIL: Multimedia Filtration
RO: Reverse Osmosis
ED: Electrodialysis

Figure 1. Process trains investigated to upgrade aluminum plant wastewater for non-potable reuse.

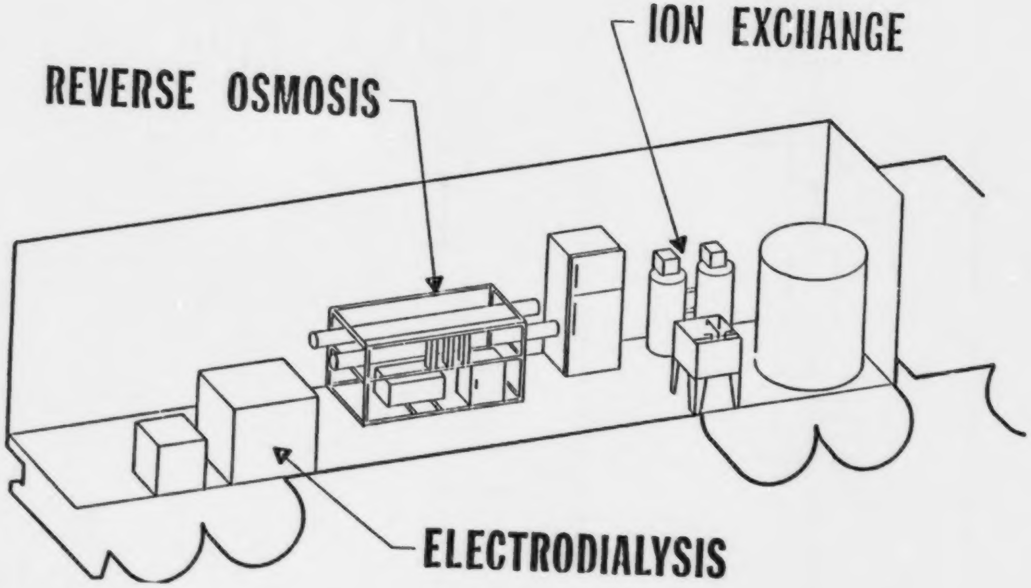

REVERSE OSMOSIS
ION EXCHANGE
ELECTRODIALYSIS

Figure 2. OWRT desalting mobile treatment van.

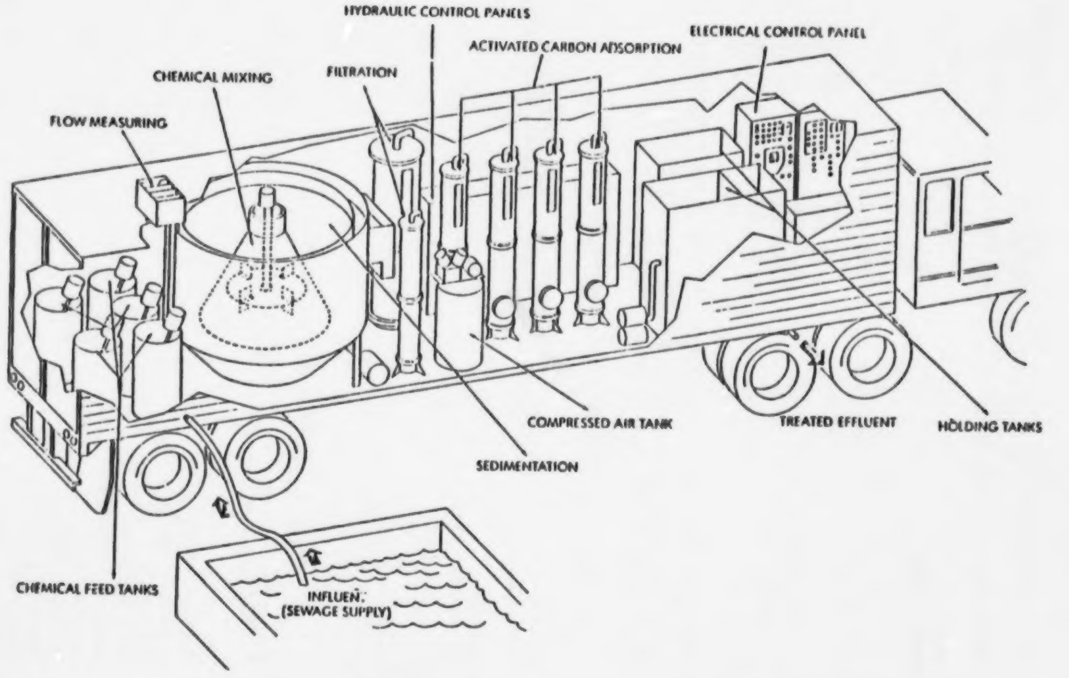

HYDRAULIC CONTROL PANELS
ACTIVATED CARBON ADSORPTION
ELECTRICAL CONTROL PANEL
CHEMICAL MIXING
FILTRATION
FLOW MEASURING
COMPRESSED AIR TANK
TREATED EFFLUENT
HOLDING TANKS
SEDIMENTATION
CHEMICAL FEED TANKS
INFLUENT
(SEWAGE SUPPLY)

Figure 3. Rexnord advanced waste treatment mobile unit.

TABLE 1. PRETREATMENT SYSTEM PERFORMANCE

Parameter	Influent Wastewater	Clarified Effluent	Filtered Effluent
pH, units	6.5-9.0	4.2-7.2	5.2-7.1
Turbidity, NTU	15.4 (106)	5.9 (106)	0.60 (71)
SS	23 (16)	15 (22)	6 (21)
VSS	11 (13)	8 (16)	4 (15)
TDS	594 (17)	565 (16)	529 (16)
TOC	<18 (13)	<11 (13)	<8 (13)
COD	53 (6)	38 (6)	28 (6)
Color, APHA units	4 (6)	4 (6)	3 (5)
Oil & Grease	26 (4)	<4 (4)	<4 (4)
TP as P	<0.26 (6)	<0.07 (6)	<0.03 (6)
NH_3 as N	6.5 (6)	5.6 (6)	4.8 (6)

All units are mg/l unless stated otherwise. ( ) indicates number of data points used to obtain average.

TABLE 2. MULTIMEDIA FILTRATION PERFORMANCE

	Influent	Effluent	Percent Reduction
Turbidity, NTU	5.9	0.6	90
Suspended Solids, mg/l	15	6	60
TOC, mg/l	<11	<8	27
COD, mg/l	38	28	26

TABLE 3. REVERSE OSMOSIS PRODUCT QUALITY

Parameter	Concentration	Percent Rejection
pH, units	4.0-4.5	
Conductivity, µmhos/cm	40-45	96
Dissolved solids, mg/l	45-50	92
TOC, mg/l	<2	67
COD, mg/l	4-5	82
Ammonia, mg/l as N	1.5-1.8	95
Sodium, mg/l	2.0-2.5	96
Calcium, mg/l	1.0-1.3	98
Potassium, mg/l	0-0.5	92
Iron, mg/l	0-0.25	79
Magnesium, mg/l	0-0.1	99
Manganese, mg/l	0-0.02	99
Fluoride, mg/l	1.0-1.2	85
Chloride, mg/l	10-12	91
Sulfate, mg/l	8-10	95

TABLE 4. REVERSE OSMOSIS BRINE QUALITY AND ALUMINUM PLANT DISCHARGE LIMITS

Parameter	Reverse osmosis brine, concentration	NPDES Permit limitations
pH, units	2.5-6.3	6-9
Dissolved solids, mg/l	1805	
Phosphorus, mg/l as P	<0.38	1.0
Oil and grease, mg/l	5	10
Fluoride, mg/l	7.29	6.0
Iron, mg/l	1.66	2.0
Chromium (hexavalant), mg/l	<0.02	0.1
Total chromium, mg/l	<0.02	0.5
Suspended solids, mg/l	15	30

TABLE 5. ELECTRODIALYSIS PRODUCT QUALITY

Parameter	Concentration	Percent Rejection
pH, units	5.5-6.0	
Conductivity, μmhos/cm	36	95
Dissolved solids, mg/l	44	92
TOC, mg/l	5	38
COD, mg/l	8	75
Ammonia, mg/l as N	<0.63	>86
Sodium, mg/l	<4.2	>93
Calcium, mg/l	<4.4	>95
Potassium, mg/l	<0.9	>74
Iron, mg/l	<0.06	>81
Magnesium, mg/l	<0.42	>98
Manganese, mg/l	<0.05	>97
Fluoride, mg/l	0.58	78
Chloride, mg/l	6	97
Sulfate, mg/l	<5	>97

TABLE 6. ELECTRODIALYSIS BRINE QUALITY

Parameter	Concentration
pH, units	5.5-6.0
Dissolved solids, mg/l	2630
Phosphorus, mg/l as P	<0.02
Oil & Grease, mg/l	5
Fluoride, mg/l	7.97
Iron, mg/l	<0.51
Chromium (Hexavalant), mg/l	<0.02
Total Chromium, mg/l	<0.02

TABLE 7. AVERAGE QUALITY OF PLANT WATER SUPPLY

Parameter	Concentration
pH, units	7.70
Dissolved solids, mg/l	368
Conductivity, µmhos/cm	500
Alkalinity, mg/l as $CaCO_3$	131
COD, mg/l	3
TOC, mg/l	<2
Chloride, mg/l	28
Sulfate, mg/l	94
Sodium, mg/l	18
Calcium, mg/l	75
Magnesium, mg/l	22
Iron, mg/l	0.07
Silica, mg/l	10

TABLE 8. POTENTIAL REUSE APPLICATIONS

Potential Reuse	Flow (mgd)	Flow m^3/day	Treatment to Meet Water Quality Requirements
Deionizer Feedwater	(1.0)	3,785	Desalting process product water
Softened Water	(0.10)	379	Desalting process product water
Process Water Cold mill and ingot plant cooling tower makeup	(1.5)	5,678	70% product water + 30% filtered wastewater[a]
Pot room noncontact cooling water	(0.30)	1,136	Direct reuse of aluminum plant wastewater
Fabricating plant coatings waste and inert gas scrubber water makeup	(0.50)	1,893	25% product water + 75% filtered wastewater[a]

a. Filtered wastewater is assumed to have chemcial clarification as pretreatment.

PB82-223561

ECONOMICAL REUSE OF WATER IN THE DRESSING OF ORES IN ARID AREAS

Anders Sellgren
Dr. Department of Metallurgical Engineering
University of Arizona
Tucson, Arizona 85721[1]

INTRODUCTION

In Arizona over 200 Mtonnes of raw sulphide copper ore are mined annually, mainly in large open pit mines. Molybdenum often occurs in the same ore as copper and is recovered as a byproduct of the copper operation. The ores are normally recovered by a flotation process.

More than one third of the ore production is concentrated in the greater Tucson area. The main water source is ground water from the so-called Tucson basin. In a forecast for the area, the total yearly use of water was estimated to be about 200 Mm^3 in the year of 2000, Griffin (1980). The relations between agricultural, mining, and urban use were estimated to be approximately 25, 25, and 50%, respectively. The total recharge of ground water was estimated to about 100 Mm^3 per year. Therefore, the depletion of ground water is expected to continue. It can not be excluded that severe water management problems will occur in the future, because of the difficulties in forecasting population growth and the amount of extractable water.

Today, the use of water in the mining industry in the area is very efficient. The make-up water requirement is approximately 0.65 m^3 per tonne of raw ore, which is low compared to international practice. However, it is expected that the industry shall be able to reduce the water requirement further. For example, in the forecast for the Tucson area, it was assumed that the water requirement in mining could decrease with 10% per tonne of ore to the year of 2000. The local situation previously discussed can be considered to be representative in many mining areas in the south-western part of the United States.

Extracting and refining ore means large amounts of non-extractable material. These residual products, so-called tailings, are deposited near the ore treatment plants. The fine-grained tailings from the ore dressing process (flotation) are normally transported by pipelines as far as several kilometers to the disposal area.

The aim of this study is to demonstrate that savings of water and energy can be made if the tailings are transported at a low water content. There are also strong environmental reasons for using less water to be released in the disposal area.

FLOW OF INDUSTRIAL WATER

After flotation of the ore, the tailings are usually thickened in permanent installations at the dressing plant. The water is then recirculated directly into the process, Figure 1. The amount of water in the tailings which are transported by pipelines to the disposal area is usually about 45 - 55% by weight. The average water requirement in the dressing process was estimated to 2.1 m^3 / tonne of raw ore by Dresher (1980). The total make-up water requirement was further estimated to 0.65 m^3 / tonne based on 80% recirculation of water. The make-up water requirement to the dressing plant was approximately 0.50 m^3 / tonne. Based on the estimations given in Figure 1, only about half the amount of water which is transported to the disposal area is directly available for recirculation to the plant. The rest is evaporated, stored within the mineral in the magazine or forms ground water.

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[1] Address after August 28th, 1981:
Department of Water Resources Engineering
University of Lulea
S-95187 Lulea, Sweden

Available estimates of the water requirement are based upon fragmentary information and should be treated with due caution. Most sources agree that the total make-up water requirement is 0.6 to 0.8 m^3 / tonne. However, how this water is lost they differ widely, Griffin (1980).

SAVING WATER AND ENERGY

The layout and design of the dressing plant affects the water supply and the flow of materials. Plants are often located so that the tailings are transported by gravity to the disposal area. The energy generated by the flow is dissipated in series of drop boxes. Therefore, no pumping energy is needed to transport the slurry, however, the water which is recirculated from the pond must be pumped back to the level of the dressing plant.

Savings in water and energy can be made if the tailings slurry is thickened effectively at the plant, which means that the tailings slurry must be transported to the disposal area with a high solid content. Large quantities of water can then be reused directly in the process instead of being transported the long way around the disposal area.

A moderate increase of the solid concentration in the pumped tailings may be very effective. For example, if a tailings slurry is pumped with a solid concentration by weight equal to 60% instead of 50%, then the amount of water which is exposed to the disposal area is lowered by 38%. If less water is exposed, then a smaller quantity is evaporated. For example, the make-up water requirement to the dressing plant is decreased about 30%, from approximately 0.50 m^3 / tonne to 0.35 m^3 / tonne, if the tailings are transported with a concentration by weight of 60% instead of 50%. Based on the estimate given in Figure 1, approximately 1/3 of the water which reach the disposal area is evaporated. The water which is stored within the magazine or forms ground water may be considered as a rechargeable resource. Therefore, the net reduction of make-up water to the dressing plant corresponds at least to approximately 10% (0.05 m^3 / tonne).

A large quantity of water is not needed to be circulated the long way around the disposal area if the tailings are transported at a concentration by weight of 60% instead of 50%. For example, in a plant with a capacity of 10 - 15 Mtonne per year and where the average ground slope down to the disposal area is $20^{o}/oo$, then the energy requirement of pumping the extra water back to the plant corresponds approximately to 0.02 kWh / tonne·km. This energy stands for about 30% of the total pumping cost of the transportation of recirculating water.

In case of no change in elevation between plant and disposal area, the tailings product has to be pumped in a pipeline. Maximum solid concentration for pumping the tailings to the magazine is primarily affected by the hydraulic characteristics of the pipeline transportation and the efficiency of the tailings thickeners. The hydraulic characteristics of transporting tailings at high solid concentrations will now be considered in greater details.

HYDRAULIC CONSIDERATIONS

The maximum particle size of a flotation tailings product is about 0.2 mm and the portion of particles less than 0.04 mm in size is about 80%. In the non-laminar flow of such a slurry, the settling rate of the solid component is small, i.e., the particles are practically uniformly distirbuted. The operational velocity of the particle-water mixture in the pipe must be high enough to ensure turbulent flow conditions, because even fine-grained industrial minerals contain traces of coarse particles capable of settling at laminar flow conditions. The range of velocities where the flow changes from laminar to turbulent conditions in a high-concentrated slurry of fine particles is very sensitive to the system rheology, which means that the mixture may behave in a non-Newtonian way. Viscometric investigations indicate changes of the hydraulic characteristics of the mixture. Viscosity is the property of a fluid which relates shear stress and shear rate and which determines resistance to a laminar flow.

Knowledge of the relationship between slurry rheology and solid concentration is necessary in order to select a pumpable concentration. The maximum pumpable solid concentration may be taken as the concentration at which a small change in concentration results in a large change in the measured viscosity. Limited laboratory bench tests of the rheological properties of fine-grained slurries and scale-up procedures to full-size pipes are powerful components in the hydraulic design of a slurry transportation system.

EXPERIMENTAL STUDY

A rotational Brookfield viscometer was used here to generate the rheological data of a representative tailings slurry from a flotation plant, Figure 2.

Details of measurement procedures and rheological analysis are omitted here. A complete description of the evaluation procedures is given in a recent report, Sellgren (1981). The so-called rheograms of two solid concentrations determined from measured data are shown in Figure 3.

With a concentration by weight of over approximately 60%, a significant change in the flow properties occurred. The viscosity increased rapidly and the slurry became difficult to agitate. It can be inferred from Figure 3, that the tailings slurry was non-Newtonian. A yield stress was observed for the high concentrations studied here.

DISCUSSION AND CONCLUSIONS

It was found in the example discussed previously, that the make-up water requirement to the dressing plant was reduced 30% from 0.50 m^3 / tonne to 0.35 m^3 / tonne if the tailings were transported to the disposal area at a concentration by weight of 60% instead of 50%. It was assumed that the flow was gravitied at an average inclination of 20 o/oo. The energy requirement of pumping the extra water back corresponded to approximately 0.02 kWh/ tonne·km.

In a similar example it is now assumed that there is no change in elevation between the plant and the disposal area, i.e., the tailings and the recirculated water is pumped in horizontal pipelines. Based on transformation of the experimental results into hydraulic design parameters then the following operational conditions are met for the pipeline transportation, Table (1)., (hydraulic procedures omitted here, for details see Sellgren, 1981).

The saving in energy by pumping the tailings at a high solid content corresponds in this case to about 0.01 kWh / tonne·km and the make-up water requirement is reduced in the same way as discussed in the previous example. Of course, the saving in energy is marginal with respect to the production as a whole, however, it corresponds to 15-30% of the cost of energy in transporting tailings and recirculating water.

It is hard to conclude how much water is in fact used in the mining and dressing operations and how this water is lost. Estimates of water losses in evaporation and seepage from the tailings ponds are uncertain and the seepage loss may vary widely with local conditions. According to Griffin (1980), who refers to measurements in the Tucson area, virtually no water seeps down into the ground water from the tailings ponds, because the flow of water is blocked by layers of fine particles settling out to form the beds of the ponds.

The average annual evaporation in arid or semi-arid areas from a shallow lake, such as a tailings pond, is 1.5 - 2.2 m^3 /m^2. The evaporation loss was estimated directly for mines in the Tucson area by Griffin, (1980). He examined the wetted areas from aerial photographs and used an evaporation rate of 2 m^3 / m^2 per year. The evaporation losses found by this method are generally greater than those given by other sources, including the estimation used here, see Figure 1.

It is therefore believed that, in fact, the evaporation stands for the larger portion and that the seepage stands for the smaller portion of the water losses at the disposal area. Therefore, there are strong reasons to conclude that the net reduction of make-up water requirement is closer to 30% than to 10% by transporting the tailings to the pond at a high solid concentration. No doubt, the possible savings in water and energy merit a detailed hydraulic design and effective control of the operation of the tailings slurry transportation system.

Environmental aspects

The disposal areas are usually bounded by earth dams. The piles of the tailings product have a marked influence on the landscape. Because dust from the disposal area is a difficult problem in many places, water is needed for dust control. Water which seeps through the tailings embankments is therefore reclaimed and used at the disposal area.

There are strong environmental reasons for using less water to be transported to the disposal area from the ore dressing operations. After the flotation process the water contains in addition to suspended mineral particles, dissolved substances from chemical additives. Today, flotation processes are carried out almost exclusively in alkaline environment, and the metal content remaining in the tailings is generally less than 0.1%. When the processing water reaches the disposal area, it may contain small quantities of heavy metals and metal ions as well as residual products from different reagents, xanthantes, terpinol, sodium carbonate, sodium bisulphite, lime hydrate, copper-, and zinc sulphates and frothing agents. Therefore, in environmental sensitive areas, advanced systems for purifying processing water is sometimes required. These will be necessary in order to decrease the total amount of discharge. Process water circulation alone does not guarantee a decrease in the total amount of pollution discharged. This amount is dependent on the additives used in the process. Recirculation of the process water via disposal ponds thus only decreases the amount of raw water required.

SUMMARY

Severe future water management problems may occur in several mining areas in the south-western part of the United States, because of the uncertainty in forecasting the amount of extractable ground water and the population growth. It is therefore expected that the mining industry shall be able to reduce the water requirement further.

The fine-grained tailings from the flotation process are transported by gravity or pumped in pipelines as far as several kilometers to the disposal area. Savings in water and energy can be made if the tailings slurry is thickened effectively at the plant, which means that the slurry must be transported to the disposal area with a high solid content. Rheological investigations of a representative tailings product and analysis of the hydraulic characteristics showed in this study, that a slurry of a solid concentration of 60% by weight was pronounced non-Newtonian but pumpable without appreciable losses.

In two schematic examples, it is shown that the make-up water requirements to the dressing plant can be reduced up to 30% if the tailings are transported to the disposal area at a solid concentration by weight of 60% instead of 50%. Besides, saving in pumping energy can be made, because extra water is not being transported the long way around the disposal area.

There are strong environmental reasons for using less water to be transported to the disposal area from the ore dressing operations. The water used in flotation processes contains small amounts of residual products of different reagents, such as xanthates, etc. Therefore, in environmental sensitive areas, purification of the processing water is sometimes required. The necessary degree of treatment is established by the water-quality requirement of the flotation process and by the existing environmental legislation.

ACKNOWLEDGEMENTS

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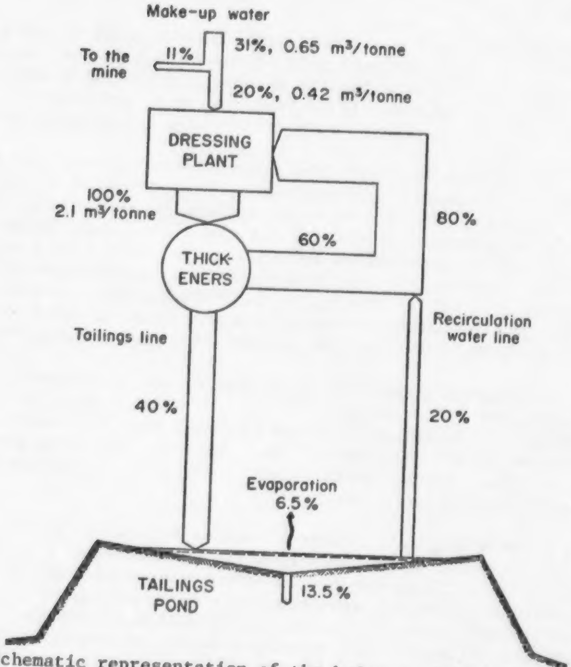
Make-up water
To the mine
11%
31%, 0.65 m³/tonne
20%, 0.42 m³/tonne
DRESSING PLANT
100%
2.1 m³/tonne
60%
80%
THICKENERS
Tailings line
Recirculation water line
40%
20%
Evaporation
6.5%
TAILINGS POND
13.5%

Figure 1. Schematic representation of the balance of industrial water in the processing of sulphide ores. Data from the greater Tucson area. After Dresher (1980).

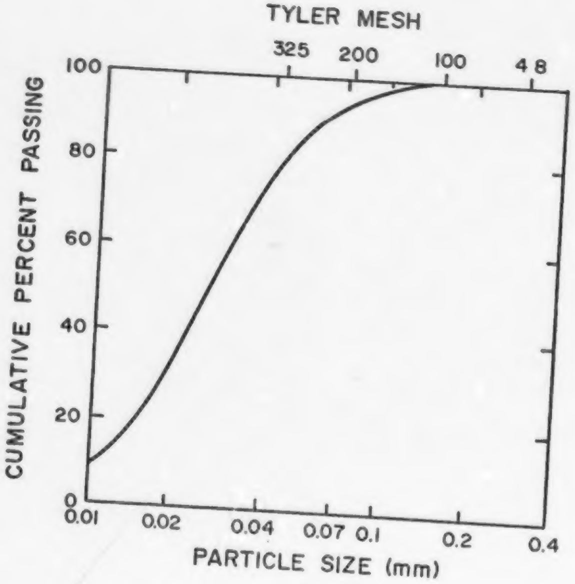

Figure 2. Particle size distribution of the tailings product used in the experimental study. The density of the solids was 2770 kg/m^3.

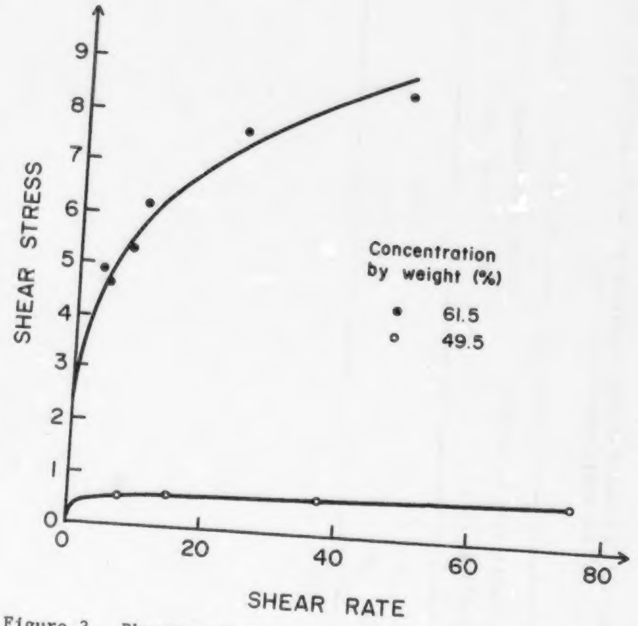

Figure 3. Rheogram for two concentrations by weight for the mine tailings slurry used in the experimental study.

Table 1. Estimated energy requirements in the pumping of tailings and recirculation of water.

Solid concentration by weight in the tailings (%).	Energy requirement (kWh / tonne · km).
50	0.08
60	0.07

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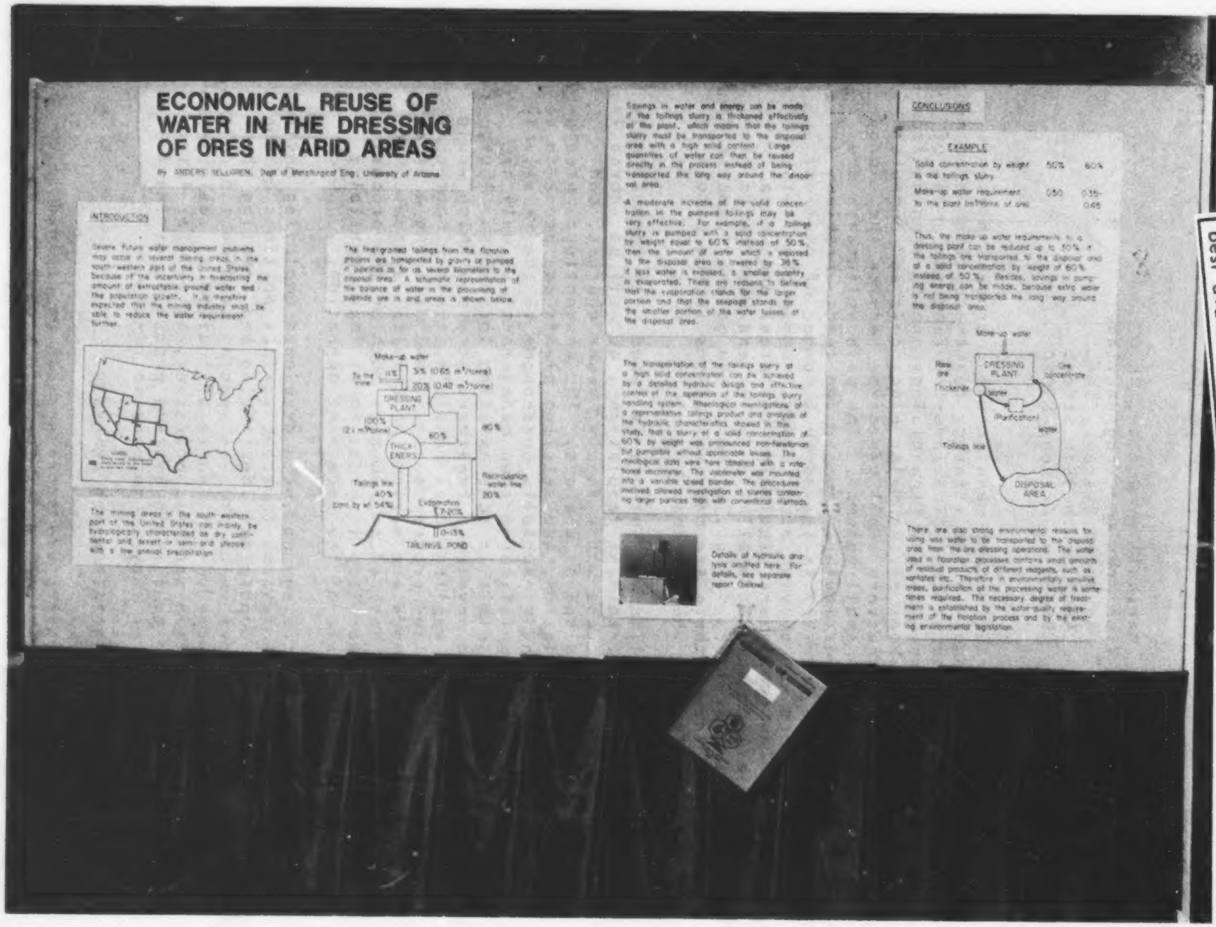

ECONOMICAL REUSE OF WATER IN THE DRESSING OF ORES IN ARID AREAS

By ANDERS SELLGREN, Dept of Metallurgical Eng., University of Arizona

INTRODUCTION

Severe future water management problems may occur in several mining areas in the south-western part of the United States because of the uncertainty in forecasting the amount of extractable ground water and the population growth. It is therefore expected that the mining industry shall be able to reduce the water requirement further.

The mining areas in the south-western part of the United States can mainly be hydrologically characterized as dry continental and desert or semi-arid places with a low annual precipitation.

The fine-grained tailings from the flotation process are transported by gravity or pumped in pipelines as far as several kilometers to the disposal area. A schematic representation of the balance of water in the processing of sulphide ore in arid areas is shown below.

Savings in water and energy can be made if the tailings slurry is thickened effectively at the plant, which means that the tailings slurry must be transported to the disposal area with a high solid content. Large quantities of water can then be reused directly in the process instead of being transported the long way around the disposal area.

A moderate increase of the solid concentration in the pumped tailings may be very effective. For example, if a tailings slurry is pumped with a solid concentration by weight equal to 60% instead of 50%, then the amount of water which is exposed to the disposal area is lowered by 33%. If less water is exposed, a smaller quantity is evaporated. There are reasons to believe that the evaporation stands for the larger portion and that the seepage stands for the smaller portion of the water losses at the disposal area.

The transportation of the tailings slurry at a high solid concentration can be achieved by a detailed hydraulic design and effective control of the operation of the tailings slurry handling system. Rheological investigations of a representative tailings product and analysis of the hydraulic characteristics showed in this study, that a slurry of a solid concentration of 60% by weight was pronounced non-Newtonian but pumpable without appreciable losses. The rheological data were here obtained with a rotational viscometer. The viscometer was mounted into a variable speed blender. The procedures involved allowed investigation of slurries containing larger particles than with conventional methods.

Details of hydraulic analysis omitted here. For details, see separate report (below).

CONCLUSIONS

EXAMPLE

Solid concentration by weight in the tailings slurry	50%	60%
Make-up water requirement to the plant (m³/tonne of ore)	0.50	0.35-0.45

Thus, the make up water requirements to a dressing plant can be reduced up to 30% if the tailings are transported to the disposal area at a solid concentration by weight of 60% instead of 50%. Besides, savings in pumping energy can be made, because extra water is not being transported the long way around the disposal area.

There are also strong environmental reasons for using less water to be transported to the disposal area from the ore dressing operations. The water used in flotation processes contains small amounts of residual products of different reagents, such as xanthates etc. Therefore in environmentally sensitive areas, purification of the processing water is sometimes required. The necessary degree of treatment is established by the water quality requirement of the flotation process and by the existing environmental legislation.

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MOVING BED ION EXCHANGE
IN CIRCUIT SHOP WATER TREATMENT

Marshall I. Gurian, Ph.D.
Vice President/Engineering
Advanced Systems, Inc.
4607 South 35th Street
Phoenix, Arizona 85040

The printed circuit board manufacturing process presents certain challenges in the strategy for the optimum treatment of process rinse waters. The industry features shops of widely differing size and financial strength, ranging from large captive shops of the major electronic and computer companies to some very small prototype service shops producing extremely small volumes. The main pollutants are heavy metals, particularly copper and lead. Problems arise because the industry is served by a number of chemical formulators who provide proprietary process chemicals containing complexers (including chelates) and whose formulations are not available to the end user or to his treatment advisers. Thus, although the general process flow is well known, there are many variations in the actual combinations of chemistries.

This industry, like many others is faced with increasingly enforced waste treatment regulations, as well as increasing expenses for process water supply, sewer charges, and chemical waste disposal charges. The conventional precipitation, flocculation, and settling plants can prove to be operationally and financially burdensome to the relatively chemically unsophisticated shop management, as well as physically impossible in some existing locations. Thus, it was desirable to develop a treatment strategy which would be as generally applicable as possible, minimizing the expense of detailed process surveys, and allowing a flexibility to accomodate a variety of chemical systems. In addition, it is desired to reuse as much of the process rinse water as possible in order to at least partially offset the expense of the treatment operation.

The resulting strategy has been developed employing moving bed ion exchange systems to treat various portions of the process stream, separately identifying and treating those major contributors which present special treatment problems. These systems include small units of individual resin types tailored to certain specific processes, as well as larger units containing dual resin systems producing demineralized water suitable for recycle to process rinses.

PROCESS CHARACTERIZATION AND ANALYSIS

The printed circuit board processes can be divided into several convenient categories for both production and waste treatment purposes. The following is representative of one class of production, namely the two sided, pattern plated, convential subtractive technology. This is certainly the most prevalent technology, and it is suitable for representational analysis. However, the variations within this technology and the alternative technologies available in some shops make comprehensive generalization difficult.

Without attempting to teach the art of circuit manufacturing it is important to examine each of these processes to identify the treatment problems presented. Since the process categories form localized production centers in the typical plant layout, this inspection can also point up specialized treatment opportunities where ease of separation of chemical systems occur. In order of their manufacturing sequence, these process categories are described briefly with their pollution contributions summarized. Further details may be found in the literature(1).

1. Mechanical Fabrication -- Deburring and Scrubbing abrasive machinery produces fine copper particulates which can dissolve when mixed with process chemicals from other areas.
2. Electroless Chemical Deposition -- Chemical cleaners, followed by tin/palladium surface activators and electroless copper reduction bath. Typically six or seven process and rinse stages comprise this area with effluent only moderate in copper metal content. There are problem complexers in these baths.
3. Image Formation -- Sometimes includes particulate formers similar to section 1. Typically, single chemical rinse from dry film photoresist process containing mild caustics and some organics, negligible metal problem.
4. Pattern Electroplating -- Usually simple acid cleaners followed by acid copper electroplating and fluoborate tin/lead alloy electroplating. Rinses moderately high in metal content and relatively free of chelates.
5. Stripping and Etching -- Stripping of pattern resist material usually high in caustic and organics, low in metals. Etching usually high in copper and ammonia. Sometimes solder activator present adding some small amounts of lead, tin, and organics.
6. Contact Finger Plating -- This is generally a small volume series of tanks to remove solder, and electroplate nickel and gold only on the contact finger area of the boards. Gold dragout reclamation usually economically demanded. Some tin, lead, and nickel contamination, but usually a very minor effluent contributor.
7. Solder Reflow -- Typically contains a chemical clean, and a water cleaning stage after flux application and infrared heating. Some tin and lead content, but generally detergent and organic effluent.
8. Final Fabrication -- Generally no wet process content.

The treatment problems presented by this type of process chemistry are further magnified by the nature of the process cycles. For example, electroless copper plating requires an immersion time of 20 to 40 minutes. Thus, one rack of boards is delivered to the rinse in a period of 10 to 40 minutes depending on the process approach. The concentration of contaminant in the rinse water has, therefore, a cyclical nature of the type illustrated in Figure 1. In most production lines, this curve is somewhat modified by the cascade rinsing procedures utilized to conserve water. The result of the combination of many processes of non-coincidental cycles is that the actual analytic picture of even a well scheduled operation is not easily defined. A typical water analysis study of a "regular conventional" printed circuit shop would therefore have to consider the time variation of many chemical species over a relatively long sampling period in order to properly specify the parameters for treatment planning. Estimates of from $5,000 to $10,000 for analysis only are not unusual. Sometimes these reports include the treatment recommendations, and sometimes they only include the process survey information. A further limitation to the rigorous analytic survey approach is that modeling changes of chemical formulations and production flows is extremely difficult and the data reflects only a composite of what occurred during the sampling period with limited expandibility.

This conventional survey approach represents a very prohibitive cost for the small to medium shop. It was, therefore, desirable to formulate a method which could be used to estimate the water contamination and treatment options with simple techniques which could be implemented with a minimum of equipment and technical expertise. A further desire was to establish a simple model which could be used to easily estimate the result of process and production changes.

The simplified description of the estimation technique is as follows:

1. Categorize all processes by type of rack used.
2. Measure dragover per square foot for each type.
3. Establish the dilution characteristic of each chemical bath.
4. Estimate the production rate.
5. Measure the flow rate of all flowing rinses. (Special techniques for conductivity controls)
6. Develop the numerical algorithm for estimation.
7. Calculate individual contributions.
8. Average (flow weighted) for gross estimate.

The implementation of the technique for a specific case can be found in summary in Table 1. For illustrative purposes, a descriptive expansion of the above technique follows:

1. There are basically two racking types used in the processes. The electroless deposition line typically utilizes a "basket" type rack into which several (10 to 12 typically) boards are inserted vertically on approximately 1/2 in. centers.

The electroplating racks are planar with clamping arrangements for current transfer to the (2 to 6) workpieces. Each company usually standardizes on its own design of the racks, and typical dragover characteristics may be attributed to each type of rack. The assumption is made that the racked panel array has a repeatable dragover regardless of which chemistry is being utilized. Obviously, there is a possibility for error, but it is not critically significant as long as there is not a highly viscous process solution being used. Most of the common processes are consistent enough for this approximation to be relatively valid.

2. The easiest method for dragover estimation is to analyze the concentration of process liquid and of a nonflowing rinse immediately following. By removing the rack from the process solution per normal procedures and immersing into a measured volume of clean rinse water, the increase in concentration of measurable contaminants in the rinse can quickly be converted into volumetric dragover. For simplicity this can be converted to a ml per square foot factor which aggregates both the workpiece geometry and rack contributions. Measured values are usually in the range of 10 to 15 ml/sq ft for the basket rack. The dragout in either case can be significantly reduced by as little as 5 seconds drain off or "hang" time over the process tank before submersing in the rinse. Of course, spray rinsing and static dragover rinsing are extremely advantageous in limiting contamination of the flowing rinses. If these methods are used, their effect can also be estimated.

3. The dilution factor for each bath can be measured in a very straight forward manner. For the simple concentration of chemical elements, a dilution of 1 ml of sample to 1 liter with distilled water is easily tested for chemical components as well as for conductivity. This gives a single analytical reference for a concentration representative of the probable range of rinse waters. Of course, the chemical results are a quantitative dilution of the bath concentrations. However, the conductivity reading is significant at this ratio. For most of the chemistries involved, Figure 2 shows that the conductivity is also a simple dilution function in a two order of magnitude range. This is specifically interesting in the analysis of contamination levels for purposes of ion exchange treatment, where the total ionic content is the treatable criterion, not merely the metals or other specific components. Furthermore, as a criterion for treatability with ion exchange, the linearity of the two decade dilution plot of conductivity implies a simple ionic character. Where there are dissociating species and colloidal character, the plots are specifically not linear or the slope is

significantly off of the "45 degree" simple dilution slope. For example, the "electroless tin" line in Figure 3.

The simple rule resulting from this discussion is that the single point (1000/1) dilution factor may be used in most of the treatable cases as a representative number for estimation purposes.

4. The production rate of the shop is merely the processed area of laminate per hour of operation. The gross square feet of laminate as purchased is used rather than using the actual wetted area for direct association with known production.

5. The flow rate of each of the rinses can then be simply measured. The problem in many shops is the difficulty of access to the outlet of the tanks because they are permanently plumbed into the drain system. In this case, the outlet or overflow can be temporarily plugged and the level increase rate measured. Where cascade rinses are employed, it is not required to analyze the dynamics of each tank, but only to get the aggregate flow rate from the final tank.

   Where conductivity controlled rinses are used, a calculated equivalent rate can be used instead of measurement. This will be explained in section 6.

6. The numerical algorithm is a method of easily correlating the basic factors of dragover, rinse flow, production rate, and concentration into an estimate of concentration or conductivity in the treatable stream. Consider the following example:

   a. Let R equal the racked dragover constant for a given configuration (ml per gross sq.ft.).
   b. Let X equal the production rate in sq.ft. per hour.
   c. Let F equal the rinse flow in liters per hour.
   d. Let M equal the concentration at a dilution of 1 ml. per liter of water.
   e. The average process dilution is then RX/F ml/l.
   f. The average rinse concentration is MRX/F expressed in units consistent with the units of M (mg per liter of particular metals, conductivity, TDS, etc.).
      Where the flow rate is controlled on a conductivity basis, there is an equivalent calculation method. If Q is the conductivity controller setting, and Mc is the conductivity at the 1 ml. per liter dilution, then the flow rate is calculated by McRX/Q. Thus, by knowing the dilution factor of the conductivity and the copper content, for example, the flow rate and the output copper content can be estimated. Where the rinse is fed by tap water rather than demineralized water, the baseline

conductivity of the source water must be subtracted from the conductivity control set point to obtain the "working" control parameter, Q.

7. The above algorithm may then be systematically employed in the analysis of each of the treatable rinses in the process line. The tabular approach in Figure 1 illustrates these calculations.

8. By summarizing the results in a weighted averaging procedure & multiplying the concentration by the flow rates, the relative contributions of each of the rinses may be examined. If the weighted result shows an unacceptably large treatment consideration, particularly important in ion exchange economics, process modifications may be possible.

At first appearance, the above procedure may seem obvious and not particularly beneficial. However, in actual plant terms, the simplicity and "aggregate" averaging can help a great deal in the practical estimation of treatment requirements. The tedium of repetitive sampling, either manually or with mechanical sampling devices, is eliminated along with the analytic expense of testing a great many samples. In addition, the analysis can be performed by relatively inexpensive techniques mastered, in most cases, by in-plant personnel even where lack of chemical sophistication exists.

Another benefit is that the dynamics of the processes are smoothed. There might be a basis for argument that the possible maximum treatment cases could be overlooked, and that it would be, therefore, possible to overload a system designed only for the average loading. The question of system consistency must be addressed on a shop by shop basis. The better managed production flows tend to attempt a balance of product flow throughout the plant. On the contrary, all shops at some times and some shops routinely run odd lots, emergency remakes, and other cases which make process loadings important. This must be a judgement in the system specification decision with the clearly economic "trade-off" of sizing for a peaking load versus the risk of overload with some frequency.

SPECIFIC RINSE TREATMENT

In the overall treatment scheme, there are at least two specific chemical usages important enough to be considered individually for isolated treatment. These areas are the ammoniacal etchant rinse and the electroless copper plating rinse. These rinses have only one element in common: Both contain significant amounts of complexers. For this reason, they pose problems in that the chemical form of the contained metals is difficult to treat, and, further, metals from other processes are tied to the free complexers rendering them difficult, also. For this reason, it is beneficial to the overall treatment strategy to separate these chemicals.

In both cases, the device utilized is a small moving bed ion exchange system called a Copperloop ® This device, when properly applied with specific process compatible resins and chemical regenerants, has proven very advantageous in dealing with these chemicals. Without belaboring the mechanical and operational details, the performance benefits and results will be discussed in both cases.

Ammoniacal Etching

Ammoniacal etching is performed by the addition of proprietary mixtures of ammonium hydroxide, ammonium chloride, and other additive ingredients (2,3) to the sump of an etching machine which contains an active etchant solution consisting of complex ionic forms of copper in the above ammoniacal system. Replenisher addition is done proportionally to copper etched in a manner which allows the continuous removal of copper from the sump in a solution having the same composition as the etching solution. The etching machinery sprays this etchant onto the circuit surface as the board travels through the appropriate process chambers. The surface of the board is continually rinsed free of copper solution. A significant treatment aspect is the accumulation of a reasonably large amount of concentrated copper ammonium solution.

In this application, the Copperloop (4) removes the copper from the rinse stream, leaving a residual below 1 mg/l. This rinse stream, containing ammonia but no significant heavy metal concentrations, may generally be discharged to accepting water works. The copper is eluted from the resin by appropriate concentrations of an ammoniacal solution resembling the etching replenisher. This elutant, amounting to approximately 3 per cent of the etchant used, is collected in the same vessel as the surplus etchant byproduct and disposed at virtually no increase in cost or handling.

The advantage is,therefore,obvious. The soluble metal is removed so that the stream does not have to be addressed by either waste treatment or complicated chemical techniques. When designing for reuse of water processed by ion exchange, this consideration is extremely important because of the difficulties that large amounts of ammonia cause in both the water purification and the final treatment areas. The system is described in Figure 4.

The benefits to be realized from the moving bed ion exchange rather than the static bed version of the technology,are significant. Because of the selection of process and rinse compatible chemistry, a rigorous washing and backflushing requirement is eliminated in favor of simple displacement rinsing. This allows a very high chemical efficiency. The periodic shifting of the resin allows a countercurrent contact operation with periods of "soaking" contact to allow efficient resin use. In addition, the equipment is always available for rinse processing, requiring neither down time for regeneration nor redundancy for process continuity. As a further benefit, the completely ammoniacal cycle avoids precipitation of copper salts in the system resulting from a lack of complexing ability if excessive water dilution were to occur.

Electroless Copper Plating

Electroless plating solutions form more of a problem than the ammoniacal etchants in the respect that there are several different complexing systems employed. This discussion is limited to one class of complexers, used in many, but not all of the electroless plating solutions marketed in the industry. The class of complexers is the alkenolamines. One popular member of the class is trade named Quadrol and forms the basis for many of the baths. The technique here described is patented (5), and licenses to use the technology are available.

There are two distinct requirements benefiting from the ion exchange treatment. The first is the recovery of both the copper and the complexing agent from the "overgrowth" of the main processing bath. Similar to the etching process, the electroless plating baths have additions of constituents continuously made to compensate for the plating process reactions. The result of these additions, is that a surplus volume of bath chemistry is generated which must be processed as a waste material. This formulation, a caustic solution rich in complexers, copper, formaldehyde, and other constituents, presents a problem from the discharge viewpoint. In addition, recovery and reuse of the complexers, which constitute an expensive portion of the chemistry make up, presents a distinct economic as well as ecological benefit.

The equipment varies slightly in resin specification and in operational configuration from the ammoniacal system. Displacement rinsing and chemical system compatibility are important features. In preliminary experimental operation, the process appears to yield a copper-quadrol elutant which has been successfully reintroduced into the bath as part of the replenishment chemistry. The complexer free process solution must still be treated to remove copper traces to levels low enough for discharge as waste water. This can most easily be accomplished by further flow through a static bed ion exchange column.

A further application of the Copperloop® in this system is the treatment of the waste waters. The benefits to the overall treatment strategy have already been mentioned, but there is an additional system compatibility which makes the combination of the "rinse loop" with the "bath loop" particularly attractive. The elution product of the "rinse loop" in sulfuric acid solution can be simply added to the overgrowth from the plating bath and reduce its pH to levels required for the "bath loop" feed stream. This benefit also allows for any copper and complexer to be returned to the recovery process. Again, the waste treatment aspect has been significantly improved. Not only has the problem chemical dragover been removed from the rinse water stream, it has been managed in such a way as to not require separate chemical treatment. This compatibility of chemical products allows the Copperloop® to represent a significant technical advantage over conventional destructive technologies. The complete electroless copper treatment system is described in Figure 5.

As a summary, these techniques are able to elegantly deal with the two largest problem rinse streams in the printed circuit shop. Although the rinse streams may be eligible for recycle through an ion exchange system, the rinse streams processed through these small exchangers now may be considered separately for direct discharge or subsequent reuse.

GENERAL TREATMENT STRATEGY -- WATER REUSE

The historical approach to water treatment in the printed circuit industry, as in many others, has addressed the sole requirement of presenting the accepting water stream with a waste water meeting specified concentration criteria. This has universally been accomplished with some version of precipitation, flocculation, settling, and sludge removal process. In some cases, the simple "end of the pipe" approach has been improved by some special destructive techniques for intermediate problem process wastes. More recently, there have been some critical shops examining the minimization of water consumption and containment procedures for eliminating the source of pollution. In nearly all cases, the forcing agency for this development has been the monitoring and enforcement of regulatory discharge limits rather than merely their existence.

As the consideration of water treatment has become more sophisticated, the desire for conservation and reuse has been examined. From the process engineering point of view, the potential danger of process contamination from recycled rinse waters is significant. Many of the processes in the circuit production are sensitive to surface cleanliness and contamination in terms of their success. Some of these problems may cause hidden defects which do not become apparent until the final assembly and testing of a finished product. When these defects occur, failure analysis is prohibitively difficult. One of the areas which have taken the share of the blame for problems is the area of rinsing. How clean is clean? How much water is the minimum necessary to provide clearly acceptable product? In the face of potential problems, the typical answer is "use all the water you can".

The constraints that this puts on the water recycle system are,therefore,important in the specification of the entire program. Very simply, the objective is to clearly attempt to eliminate the possibility of undesirable cross contamination in the recycled water stream. This can be accomplished in three ways. First, all possible problem chemistries can be eliminated from the rinse waters either by process exclusion or by process changes to more acceptable standards. Second, attempt must be made to design enough redundancy and instrumentation to eliminate the possibility of trace chemical build up. And third, the recycled waters must be programmed to be used by those processes which will be insensitive to minor system operational problems.

A further condition for the system is that the final treatment characteristic be economical, well controlled, and offer some improvement over the traditional continuous precipitation processes. It is not within the scope of this work to consider all of the alternative final treatment schemes. Therefore, the final concentration of metal and other contaminants is still to be treated by precipitation. However, it is desirable to minimize the size and expense of this operation as part of the overall treatment justification.

Moving Bed Ion Exchange

The principal reconstitution device selected for the manufacturing of water suitable for reuse is a dual moving bed ion exchange system. This device was selected because of the potential for separation of the rinse and regenerant streams, the effective use of regenerants, and the relatively small amount of contained resin for a given treatment rate. In addition, the continuous operation of the system with "real time" regeneration offers minimal process interruption for regeneration downtime. The basic resin treatment system is illustrated in Figure 6.

Before the water contacts the working resins, extensive pretreatment must be done. Cartridge filters are used to remove particulates which might be trapped in the resin causing difficulty in exchange and in bed motion. A carbon bed is used as the first stage of pretreatment to remove trace organic contaminants. Following this, there is a resinous absorbant to remove any remaining organics. This bed, which is essentially regenerable, removes the type of organics which readily contaminate the anion exchange resin. By combining the effects of the carbon and resin absorbers, the risk of resin poisoning is minimized and the level of organics appearing in the recycled stream is reduced to acceptably low limits.

The ion exchange beds are composed of conventional resins. The strong acid and strong base resins are designed to fundamentally demineralize the water. The "folded" column bed design allows a bed motion technique which is very gentle in its mechanical stress of the resin. Moving only a portion of the resin complement at any one time, the pneumatic and slurrying motion technique has proven successful in providing for minimum resin degradation.

One of the fundamental system design parameters is the definition of the ionic loading which will give successful and economic performance. The predicted chemical usage and chemical regeneration cost are listed in Table 2. One problem in estimating the actual ionic loading is the difficulty in analysis of the total ion content of each stream. It was decided early in the program that the conductivity of the streams would serve as the reference for sizing purposes, using the sodium chloride ionic conversion to chemical equivalency for conservative sizing purposes.

Another system decision was to attempt to contain a minimum amount of resin. This would be advantageous from at least two aspects. The first is that vessel size and, therefore, system size and cost would be minimized. The second is that resin cost would not be excessive in the event of contamination forced replacement. One consequence of this decision was the possibility that some mobile ion bleed through would occur. This meant that the target output quality for recycle to the processes would be somewhat less than that of "pure" deionized water. It was decided that the water target specifications would be (a) water conductivity less than 50 micro-mho/cm (greater than 20,000 ohm-cm resistivity) and (b) pH between 4 and 10. The pH specification, while seemingly very loose, is really not excessively wide. At the low conductivity levels specified, the slight imbalance in ionic bleedthrough could cause this variation in pH. Note that a few millimoles per liter of sodium bleedthrough in excess of the anionic contribution could raise the pH to 10. Certainly, the low conductivity water presents no contamination problem and is superior in most cases to the rinse waters in most installations.

Combined Treatment -- Reuse Strategy

The strategy outlined here is a general one; suitable for treatment of most "conventional" circuit shops. Each shop must be analyzed bath by bath to determine desirability for minimum risk introduction to the reuse system. The general system diagram appears in Figure 7. Each process area in this example is treated ideally. It is assumed that cleaning stages are substantially chelate free and are thus eligible for reuse treatment. It may be noted that many of the processes have alternatives presenting more suitable chemicals for reuse. For example, ammonium persulfate surface etching processes can be replaced easily by hydrogen peroxide-sulfuric acid baths with virtually identical product performance and substantial improvement in treatability. Similarly, replacement of ammoniacal etching with alternative chemical formulas, such as another version of the peroxide-sulfuric acid formulation, can eliminate the ammoniacal treatment problem and allow more water reuse. The problems thus avoided are the minimization of ammonia in the recycled stream (it has a potential for breakthrough) and elimination of the effects of complex ion formation inhibiting the waste precipitation portion.

The treatment strategy is then straight forward. The processes which are not elected for ion exchange and recycle are summarized as follows: (1) Particulate formers -- waters are filtered and returned to rinses; (2) Rinses with major organic components (and negligible metals) -- rinses to final pH adjustment and discharge; (3) Ammoniacal etcher rinses -- treat with Copperloop and discharge to final pH adjustment; (4) Electroless copper rinses -- treat with Copperloop and discharge to final pH adjustment; (5) Heavily chelated rinses which contain metals -- special destruction required; (6) All remaining rinses may be collected for ion exchange processing. A seventh category (dragout rinses) has been included in Figure 7. This group reflects a reality in the ion exchange strategy that the economics of processing are extremely unfavorable if the contamination levels are excessive. If a minimum flow rate (a few gallons per day) rinse or a low volume spray or mist rinse is used immediately after the process station, the contaminant level in the flowing rinse may be reduced by a factor of 10 or more. Such applications require treatment in the precipitation system, but improve the processing economics and stability of the ion exchange system to the extent of completely altering the feasibility decision.

The "Hydroloop"® moving bed system is preceeded and followed by process tanks sized to contain at least one hour of process flow. The tanks are provided with several level controls which maintain logical flow for all contingencies. For example, if the production lines were shut down and were not demanding water, the "clean tank" would fill until its high level sensor shut down the ion exchange system. Similarly, a low level in the "dirty tank" would cause a tap water refill to occur. Water for rinsing the resin is taken from the "clean tank". This reduces the actual water return to the process to between 90 and 95 per cent of the rinse water accepted, but provides the benefit of a system purge which limits the build-up of residual contaminants.

The true benefits of moving bed exchangers are realized when the final treatment sections are considered. The only contaminant containing streams requiring metal removal treatment are the regenerant concentrates and the dragout rinses. These may be readily contained and precipitated in a batch fashion. The advantage is that continuous flocculation is not necessary. The batch mode allows precise chemical dosing, making feasible the treatment with successive doses of specifically effective chemistries, which allow very low limits of effluent contamination. For example, a hydroxide precipitation might be followed by a sulfide treatment to force metal ion content to extremely low levels. Settling in this system can be allowed to take place for a long period, particularly if a dual collection system is employed. Sludge dewatering can take place in a filter press after decantation of the metal free water.

The water is then mixed with the balance of the process streams for final pH adjustment before discharge. The rinse streams from the resin beds are simply added to this stage of treatment, because they only contain residual regenerants and not contamination from the sorbed process ions.

It can be seen that a comprehensive process strategy has been developed to treat the waste problem,while at the same time providing a reusable water stream. It is not an easy application to the production process since there is some interaction and interference with the traditional operation and plumbing practices pervading most shops. However, in the coming decade, the combination of treatment limitations and water availability and costs will make the consideration of more complex but comprehensive strategies mandatory.

OPERATIONAL EXPERIENCE

There have been several installations of this type of ion exchange equipment to date. The early installations all suffered from lack of knowledge of the subleties and limitations of the applications problems, as well as some underengineering of the actual hardware. After Advanced Systems acquired the license for the manufacture and sale of this particular equipment technology, a substantial hardware redesign and applications study were undertaken. The concepts discussed above have resulted from learning from the early applications experience. Particularly important was the appreciation of the concentration limits for total contaminants as related to real process dragout practices.

System Performance

The most representative installation utilizing these concepts was started in a small European shop in December of 1980. A process analysis performed according to the principles outlined above is summarized in Table 3. The production flow was entirely conventional, with the etching process being the hydrogen peroxide--sulfuric acid chemistry. Because the production volume was small, there was no requirement for dragover rinses. A flow schematic giving the relative tank sizes and floor space is illustrated in Figure 8. It will be observed that a very small floor space is dedicated to the entire water treatment facility.

Outside of the normal amount of minor mechanical debugging of the equipment, the processing experience has been favorable. The average input conductivity of rinse waters into the system is about 450 micromho/cm. The clean product water returned to the processes is below 50 micromho/cm and is delivered from the unit at about 57 liters/min (15 gpm). The carbon and particulate filters are renewed on a biweekly cycle or less frequently. To date, there has been no indication that process contamination has occurred, even though some potentially deleterious organic containing rinses were not excluded from the recycle stream. It is still too early to know the extent of any resin degradation from organic contamination, but it is believed to be neglibible.

A major difficulty in analysis of the performance of this installation is the character of the operation and is typical of circuit shop installations. There is no chemically trained operating person employed by the owners of the equipment. Therefore, although operations personnel are maintaining the mechanical performance of the device, the chemical performance has not been closely monitored. Paper chart records of the pH and conductivity of the feed and product streams have been preserved, but the proper annotation discipline relating charts to dates and process parameters has been weak. Certainly, there has been no indication of process problems related to water, but detailed analysis of the chemical stream, particularly of organic contamination levels, has not been performed. There has also been no feedback regarding the performance of the waste treatment portion of the system, which was designed and installed by a local firm. It has to be assumed that the relatively stringent pollution requirements of the local water authority have been met.

Economic Justification

Until now, all of the cases where the decision to employ the moving bed approach has been taken have several common elements. There was extreme pressure in several respects. First, the effluent contamination limits were stringently enforced and the concerns involved were threatened with large fines or shut down. Secondly, most cases had a strong limitation on fresh water supply capacity. A third consideration, particularly critical in the above European case, was the extreme lack of facility expansion floorspace, which dictated a compact sizing to the final treatment system. This criteria forced the treatment of only a small quantity of waste, which encouraged water reuse as a required technology. Furthermore, the company was bound by an extremely rigid facility lease and occupied the third floor of a small industrial building. Forced by strong enforcement of discharge standards and having no expansion or moving options, the economic decision was completely secondary to finding a technically feasible solution.

In the United States the individual shop decisions are more complex. The economics cannot be simply stated because the variation from case to case is too great. In most cases the decision is made on the basis that any water treatment is an overhead expense related to potential or actual regulatory pressure. Since there is little perceived production benefit, the decision is often made on a minimum cost and inconvenience basis, rather than technical merit. In general, the water savings alone cannot justify a reuse system. However, for new plants in the "Twin Cities" area of Minnesota, there is an inducement because of the high per gallon charge for both water supply and sewer hookup. One possible advantage is for those concerns which may reduce their effluent discharge from a relatively high volume to below 10,000 gallons per day, and thereby change the category of regulatory standards which must be met. Unfortunately, most of the local water districts do not follow this area of the Federal EPA code. They simply enforce their total concentration limits and thus present no incentive for reuse. Of course, there are some areas of the country which absolutely prohibit discharge of any industrial effluent, and thus apparently encourage reuse. Usually, this extreme limitation has the effect of discouraging industry to the degree that the plant sites are vacated.

SUMMARY

In summary, it is technically feasable to recycle a major portion of the rinse waters from printed circuit production shops with a minimum amount of process modification.

However, there remain some process chemical formulations which remain untreatable in a closed loop manner. The production justification for the purified rinse water must be balanced against the potential for process contamination. It is obvious that economic incentives for water reuse in the form of tax credits, water cost credits, low interest loans, and other creative methods would shift the focus of much of the industry to more active consideration of this potential.

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3. Gurian, M.I. "Steady State Regenerative Etching: A Technology Review," Electronic Packaging & Production 18, 7 pp. 32-36.

4. Gurian, M.I. "Ion Exchange Separation Method", U.S. Patent; 4,269,716;1981.

5. Zeblisky, R.J. "Treatment of Liquids Containing Complexed Heavy Metals and Complexing Agents", U.S. Patent 4,076,618;1978.

Table 1
Process Rinse Analysis -- Medium Production Shop

Rack Dragout (R):
A. Flat Rack (5.25 sq.ft. contained) -- 12 ml/sq.ft.
B. Basket Rack (78 sq.ft. contained) -- 35 ml/sq.ft.
Production Rate (X): 70 sq.ft./hour (5000 sq. ft./week)

PROCESS	FLOW (F) l/hr	RACK	DR.OUT (RX) ml/hr	Std COND (M) $	Avge COND (RXM/F) $	Wtd COND (RXM) $$
Acid Cu Plt	340	FLT	840	1600	3950	1.34
Sn/Pb Plate	340	FLT	840	1700	4200	1.43
Acid Clean	230	FLT	840	250	913	.21
Rev.Ct. Cln	450	FLT	840	1300	2425	1.09
Pre Etch	450	BSK	2450	1200	6350	2.94
Cat/Accel	680	BSK	2450	100	360	.24
Eltrlss Cu	570	BSK	2450	250	1074	.61
Final Etch	1360	BSK	2450	1100	1981	2.70

Total Flow: 4420 l/hr (19.5 gal/min)
Flow Averaged Conductivity: (2390 micromho/cm)

$ units of micromho/cm
$$ units of mho/cm

Note: Rinses included in this table represent the candidates for reuse, and not all rinses in the shop. This facility represents a low water usage shop. By implementation of dragover and spray rinses, a concept was developed to reduce the flowing stream conductivity by nearly a factor of five.

Table 2
Operating Summary, Hydroloop Moving Bed Ion Exchange

	Input Conductivity, micromho/cm			
	150	300	450	600
Ion content, meq/l	1.3	2.5	3.8	5.1
Rated Flow, gpm	25	25	17	12.5
Recycle Flow, gpm	24.2	23.5	15.6	11
Recycle Flow, %	97	94	92	88
Regenerant Use				
Acid, 8 Hr, gal	36.8	73.6	73.6	73.6
Caustic, 8 Hr, gal	44.7	89.6	89.6	89.6
Chem. Cost, 8 Hr, $	10.56	21.12	21.12	21.12
Total Treatable Concentrate, gal/8 hr	92	184	184	184
Cost per 1000 gal, $	.91	1.88	2.93	4.08
Cost per cu. mtr., $	.24	.49	.78	1.06

Note: Regeneration capacity limits this particular design to an input conductivity of 300 micromho/cm for full rated flow. At higher conductivity, the flow is be derated to maintain the proper regeneration characteristics. It is believed that the economic and practical limit of application is 450 micromho.

Table 3
Process Rinse Estimate — Small Production Shop

Rack Dragout (R):

- A. Flat Rack — 120 ml/sq.m.
- B. Basket Rack — 200 ml/sq.m.
- C. Unracked, Conveyorized — 60 ml/sq.m.

Production Rate (X): 1.43 sq.m./hour (2000 sq.m./year)

PROCESS	FLOW (F) l/hr	RACK	DR.OUT (RX) ml/hr	Std COND (M) $	Avge COND (RXM/F) $	Wtd COND (RXM) $$
Alk Clean	230	BSK	286	18	23	5
Sul/Prx Etch	460	BSK	286	1200	746	343
Catalyst	460	BSK	286	660	410	189
Accelerator	230	BSK	286	100	124	29
Eltrlss Cu	230	BSK	286	250	310	72
Acid Cu Plt	345	FLT	172	1600	800	275
Sn/Pb Plt	345	FLT	172	1700	850	292
Acid Clean	230	FLT	172	25	19	4
Develop	230	CON	86	30	11	3
Sul/Prx Etch	460	CON	86	1200	224	103
Brighten	230	CON	86	100	37	9

Total Flow: 3400 l/hr (15 gal/min)
Flow Averaged Conductivity: 389 micromho/cm

$ units of micromho/cm
$$ units of millimho/cm

Note: These estimates are aggregates; the actual operation showed typical 450 micromho content with a baseline of 40 micromho in the reuse waters. Thus, the gross estimate produced above was within 10 percent of actual experience.

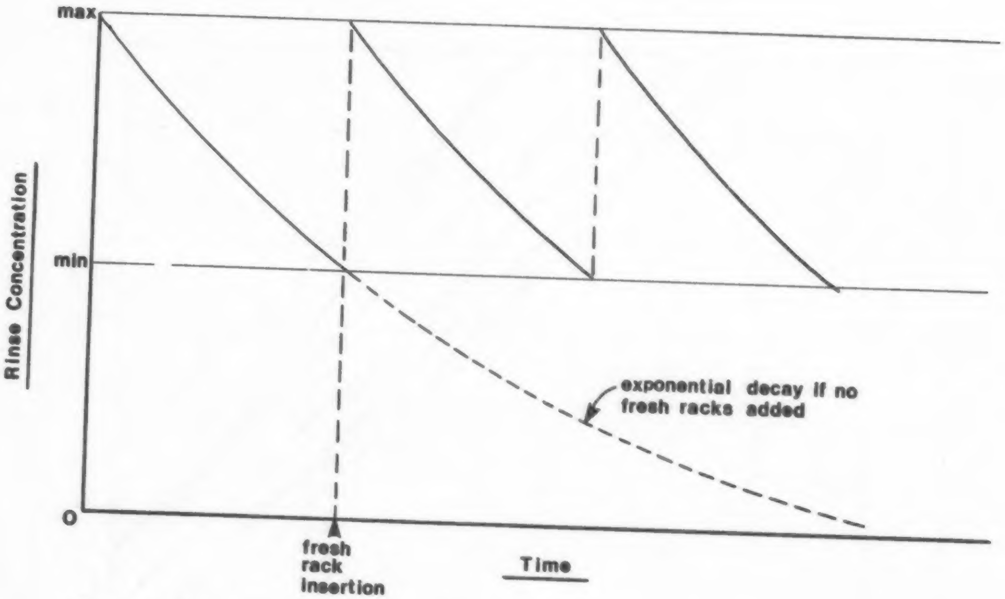

Figure 1 Concentration Profile - Flowing Rinse with Periodic Product Insertion

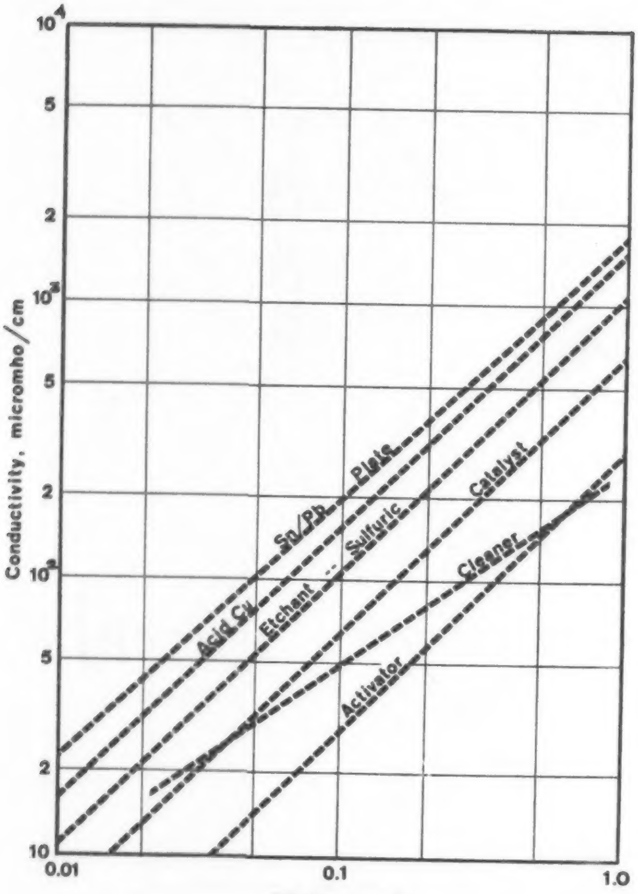

Figure 2 Conductivity Curves - Near Ideal Process Solutions

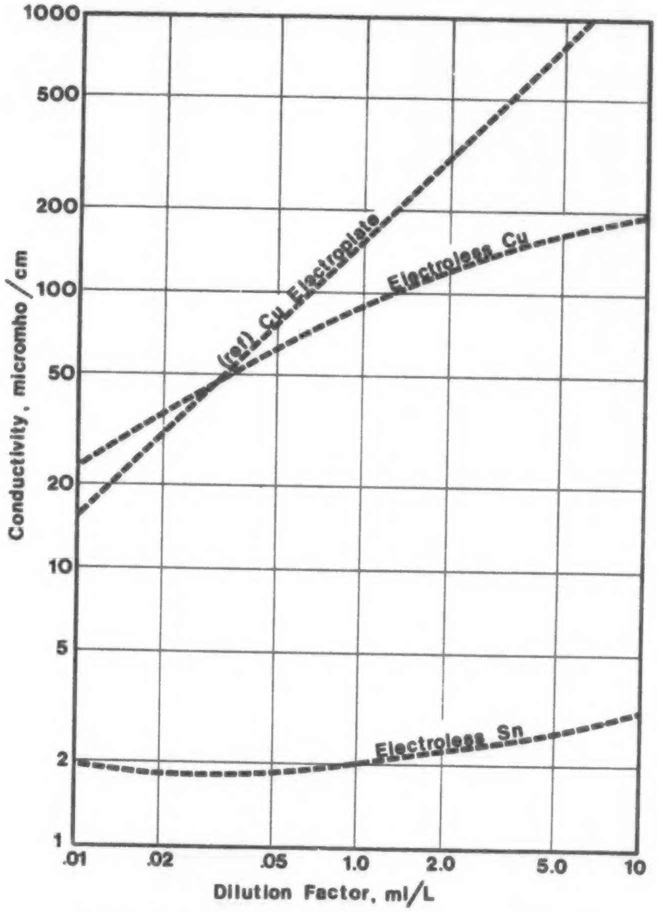

Figure 3 Conductivity Curves - Non Ideal Solutions

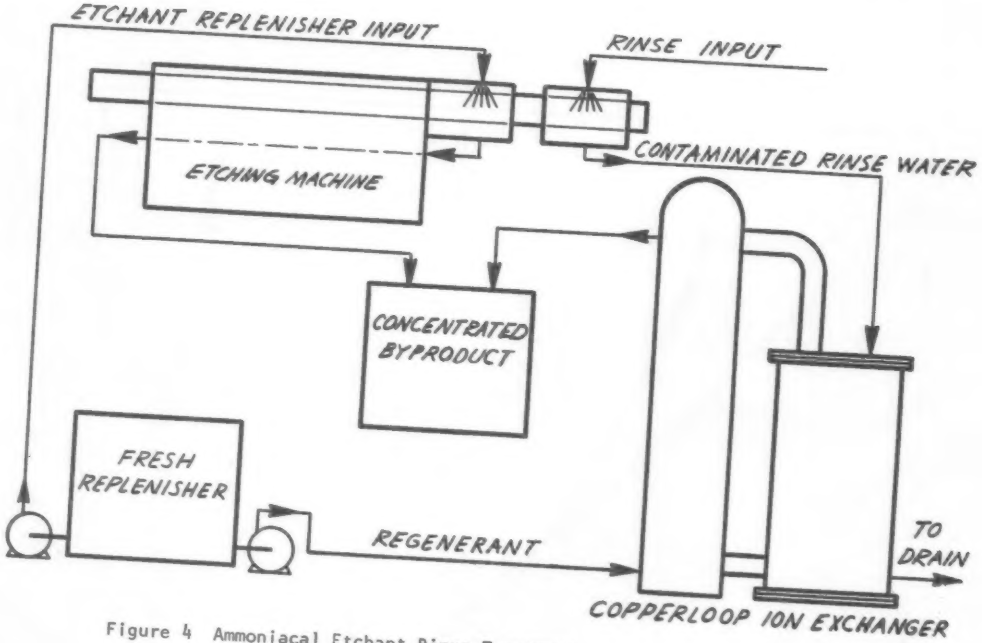
ETCHANT REPLENISHER INPUT
RINSE INPUT
CONTAMINATED RINSE WATER
ETCHING MACHINE
CONCENTRATED BYPRODUCT
FRESH REPLENISHER
REGENERANT
TO DRAIN
COPPERLOOP ION EXCHANGER

Figure 4 Ammoniacal Etchant Rinse Treatment

]

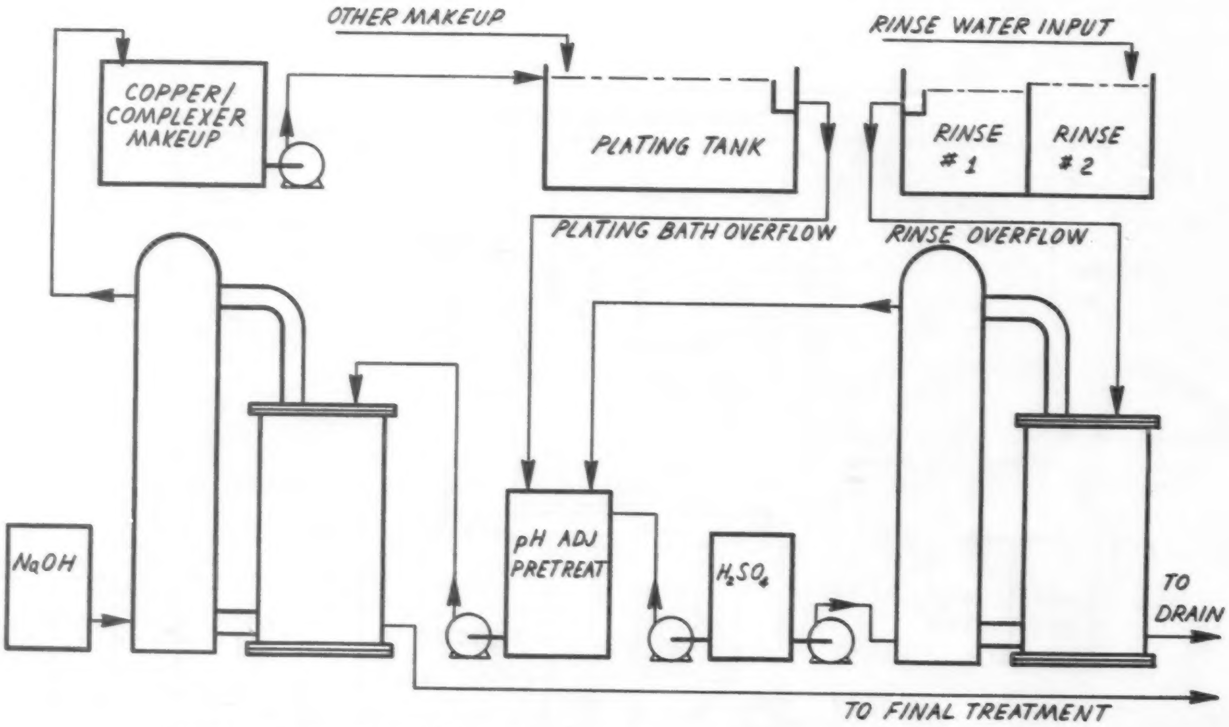
OTHER MAKEUP
RINSE WATER INPUT
COPPER/ COMPLEXER MAKEUP
PLATING TANK
RINSE #1
RINSE #2
PLATING BATH OVERFLOW
RINSE OVERFLOW
NaOH
pH ADJ PRETREAT
H_2SO_4
TO DRAIN
TO FINAL TREATMENT

Figure 5 "Quadrol" Bath Electroless Copper Combined Treatment

9 OF 9

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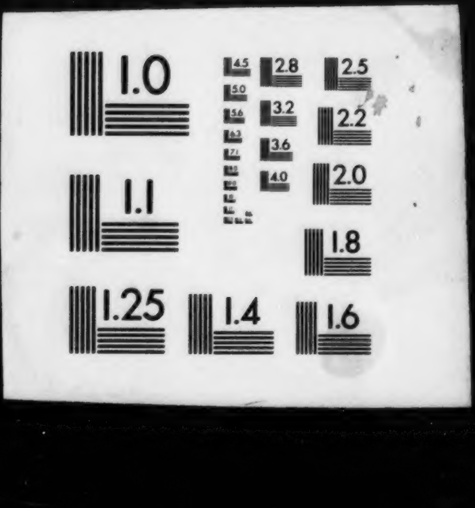

1.0
4.5
2.8
2.5
5.0
5.6
3.2
2.2
6.3
7.1
3.6
2.0
4.0
1.1
1.8
1.25
1.4
1.6

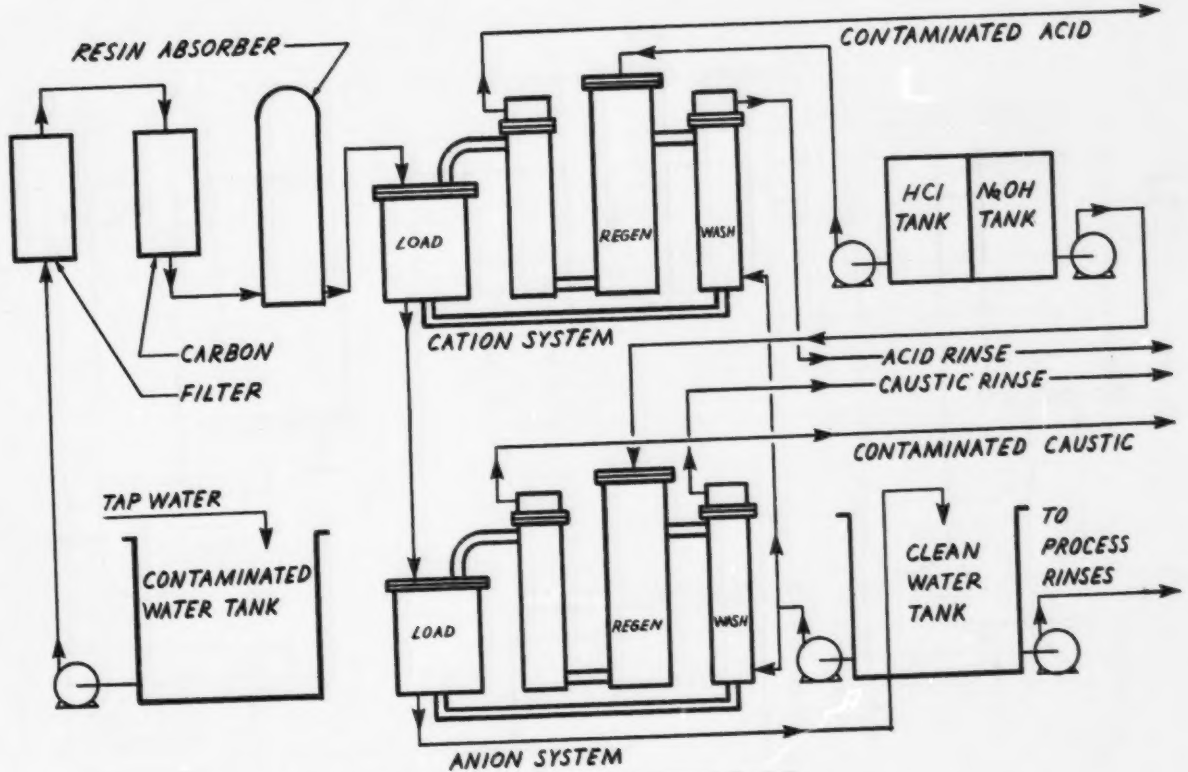

RESIN ABSORBER
CARBON
FILTER
LOAD
REGEN
WASH
CATION SYSTEM
HCl TANK
NaOH TANK
CONTAMINATED ACID
ACID RINSE
CAUSTIC RINSE
CONTAMINATED CAUSTIC
TAP WATER
CONTAMINATED WATER TANK
LOAD
REGEN
WASH
ANION SYSTEM
CLEAN WATER TANK
TO PROCESS RINSES

Figure 6 Moving Bed Ion Exchange Water Treatment System

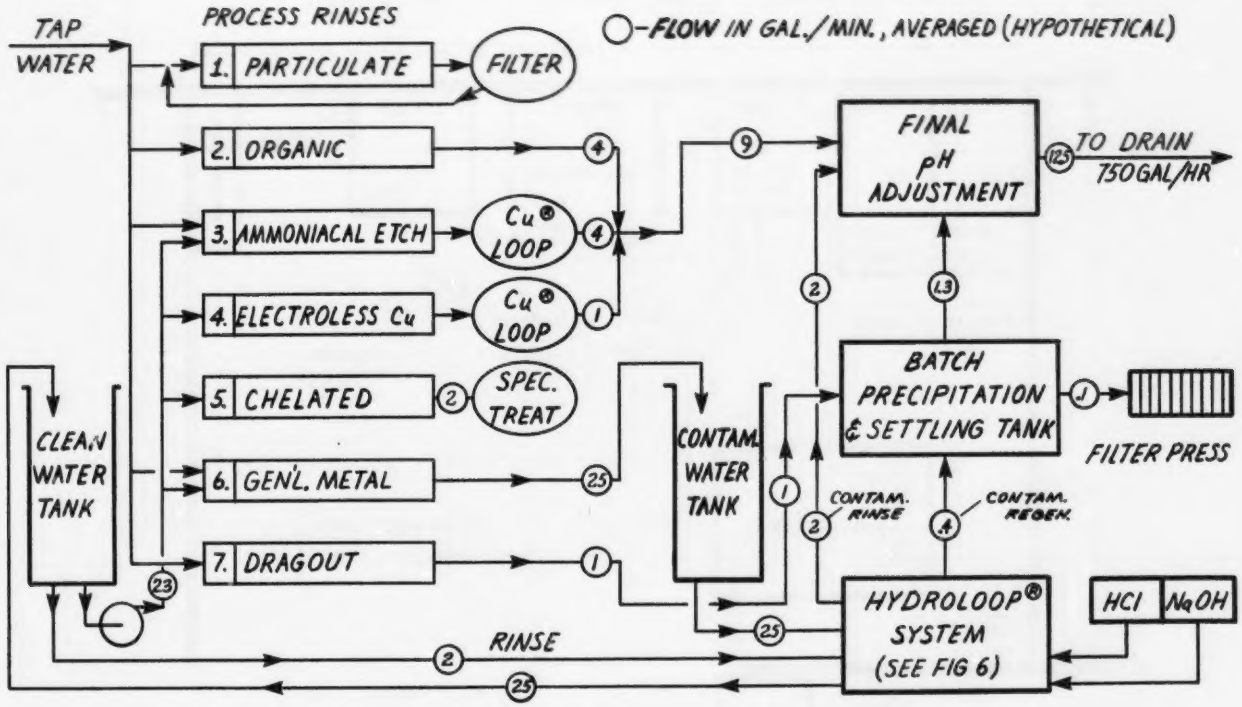

TAP WATER
PROCESS RINSES
○-FLOW IN GAL./MIN., AVERAGED (HYPOTHETICAL)
1. PARTICULATE
FILTER
2. ORGANIC
4
3. AMMONIACAL ETCH
Cu® LOOP
4
4. ELECTROLESS Cu
Cu® LOOP
1
5. CHELATED
2
SPEC. TREAT
6. GEN'L. METAL
25
7. DRAGOUT
1
9
FINAL pH ADJUSTMENT
12.5
TO DRAIN 750GAL/HR
2
1.3
BATCH PRECIPITATION & SETTLING TANK
.1
FILTER PRESS
CLEAN WATER TANK
23
CONTAM. WATER TANK
1
2
CONTAM. RINSE
.4
CONTAM. REGEN.
HYDROLOOP® SYSTEM (SEE FIG 6)
HCl
NaOH
25
RINSE
2
25

Figure 7 Printed Circuit Rinse Strategy with Reuse and Treatment

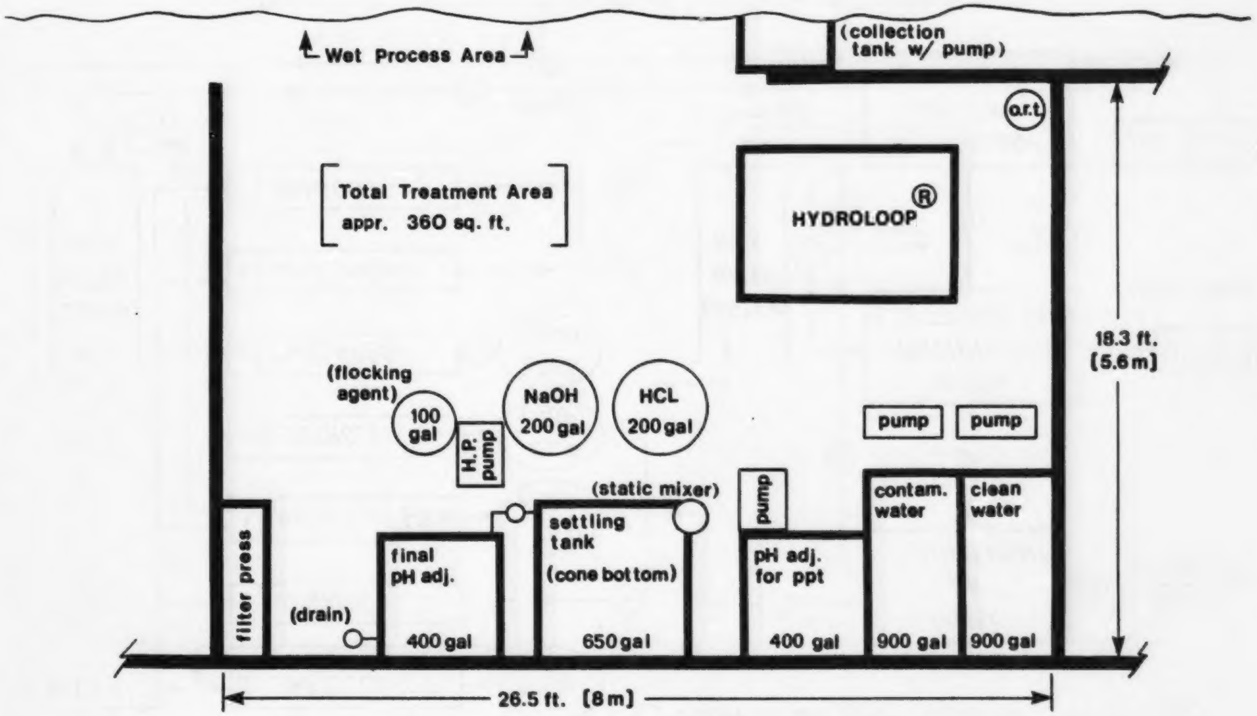

Wet Process Area
(collection tank w/ pump)
o.r.t.
HYDROLOOP®
Total Treatment Area appr. 360 sq. ft.
18.3 ft. [5.6 m]
(flocking agent)
100 gal
H.P. pump
NaOH 200 gal
HCL 200 gal
pump
pump
(static mixer)
pump
settling tank
(cone bottom)
650 gal
final pH adj.
400 gal
pH adj. for ppt
400 gal
contam. water
900 gal
clean water
900 gal
filter press
(drain)
26.5 ft. [8 m]

Figure 8 Small Shop Treatment Floor Plan - Actual Installation

PB82-223587

PRINTED CIRCUIT BOARD RINSE WATER RECYCLED BY ION EXCHANGE

Greg Allan
Project Engineer
Chem-Nuclear Systems, Incorporated
Bellevue, Washington 98009

Andy Wipplinger
Facilities Engineer
The Boeing Company
P.O. Box 3707
Seattle, Washington 98129

INTRODUCTION

The rinse water from a new, small printed circuit board manufacturing facility has been recycled with the aid of conventional pressure filters and ion exchangers.

A pressure sand filter, activated carbon filter, cation and anion exchangers, mixed cation and anion exchanger and a cartridge filter, are the principal treatment equipment. The treatment system is complete with instrumentation and operating procedures to ensure constant quality.

Careful consideration of the wastewater and make-up chemistries, flow charateristics, equipment design and operating parameters has achieved better than 90% rinse water return and a reduction in capital and operating costs over more conventional systems. This paper summarizes these design considerations and gives a brief operating history.

DESIGN CRITERIA

The most efficient treatment system begins with a thorough design criteria, or definition of the problem. The major items making up the criteria, in their order of importance are the following:

1. Waste effluent limitations of the facility
2. Waste charaterization - flows and chemistry
3. Water quality demanded by the process
4. Physical limits of the facility
5. Operational simplicity

Items 1 and 2 are dependent upon the design and use of the circuit board manufacturing facility. Since the manufacturing and waste treatment systems were all new, defining Items 1 and 2 were difficult to fix.

Effluent Limits

The effluent guidelines issued by the local Publicly Owned Treatment Works (POTW) specified zero discharge of heavy metals from a new manufacturing facility. Discharges to the sewer could only include approved detergents, other organics and solids. The discharge to sewer had to be above a pH of 6.5. All wastes emanating from the facility and not discharged to the sewer were hauled away by a licensed chemical disposal site.

Waste packaging was narrowed to 55-gallon drums and 3000 gallon tank trucks. Waste hauled by tank truck was costing 35¢ oer gallon at the time of design and was projected to rapidly increase (today it is about 50¢ per gallon). It was apparent that waste handling costs would be a major operating expense.

Rinse Water Characterization

The first step in characterizing the many rinse water streams was segregating them into specific groups. The criteria for the different rinse water groups was their size, chemistry and treatability. Volume, concentration, haul-out frequency, chemical compatibility, etc., were all considered when segregating rinse waters.

Table I summarizes the major rinse water streams, volumes and disposition.

Rinse Tank Design

The rinse tanks themselves are double counter current type with conductivity control of rinse water quality. This tank design is shown in Figure I and was derived from the following requirements:

1. Minimize cross contamination of process tanks
2. One-tenth the water flow for a given water quality
3. Flush time of rinse contaminant is negligible
4. High quality and consistency of rinses.

The rinse tanks are approximately 1-1/2 x 2' x 2'. Each tank can flow up to 1 gallon per minute which is the required flow of a single compartment rinse tank. A tenth of a gallon per minute would be typical of this size double counter current tank. A total of 31 rinse tanks contribute 40 gallons per minute to the rinse water treatment system. Water flow rates were considered a fixed variable in the treatment plant design.

Tank Design Philisophy

Rinse tank design was considered on an integral part of the waste treatment design. Rinse tanks determine the flow for given tank influent and effluent qualities.[1] Therefore, rinse tanks determine the economic size, and to a secondary degree, type of treatment system.

Other Flow Sources

As Table I indicates, there are 3 minor contributors to the treatment system. The circuit coard etcher operates on a batch basis and makes a sudden demand for 25 gpm for up tp 50 minutes. The etcher also employs water saving rinse tanks. The fume scrubber operates continuously and uses a water spray to remove the heavy metal laden water vapor. The alodine operation is an aluminum treatment process not associated with the circuit board facility. Alodine rinses were incorporated at the request of the POTW officials.

Rinse Water Chemistry

Obtaining a detailed chemical make-up of the rinses was the most difficult part of the design criteria. The new circuit board facility was replacing an old one. Some information could be derived from the old facility such as total process fluid drag-out or drag-out per board. However, the old facility utilized single rinse tanks, poor quality rinse water and some processes were scrapped. In short, the old facility could be used for the basis of a material balance of the new facility but not for a direct analysis.

An attempt was made to list all rinse tanks and perform a rigid material balance on them based on known dragout figures. This would work for a constant production volume. In this case, not only was the production rate highly variable but detailed chemical make-up of all 29 proprietary process solutions was not possible to obtain.

Assumptions were made for the worst case. The highest flow would occur when all rinse tanks are operated as single tanks rather than the water saving double counter-current method. The worst case rinse water chemical make-up was determined by the following steps:

1. The total dissolved material carried out of the process tank to the rinse tank, per circuit board, was assumed the same between the old and new facility. The drag-out was determined from the average combined effluent analysis and the average process tank solution strength.

2. Given the quality desired in the final rinse, the volume of the rinse tanks, the drag-out amount per board and the average strength of the process solutions the minimum tank flow and maximum total effluent concentrations could be determined (TDS,TOC, total metals).

3. Concentrations of rinse water elements were determined from their estimated fraction in the process solution and then their fraction of its rinse tank out of the total number of rinse tanks.

4. The organics were assumed to be all of those normally present in metal finishing solutions.

5. The total suspended solids (TSS) were unknown. The levels were assumed insignificant.

TABLE I

RINSE WATER SEGREGATION

RINSE WATER TYPE	VOLUME %	FLOW (GPM)	DISPOSITION
Gold Plate	<1	<.5	Dedicated Gold Recovery System
Free Cyanide Bearing	<1	<.5	Dead Rinse, Haul-Out
Floor Wash Down	<1	Intermittent	Haul out or sewer depending on analysis
Sinks & Misc.	≈10	Intermittent	To sewer with approved detergents only.
Fume Scrubber Water		5	Rinse Water Treatment System
* Alodine Rinse Water (Chromic acid base)		Variable 5	Rinse Water Treatment System
Circuit Board Etcher		Variable 25	Rinse Water Treatment System - High Flow Condition
Auto Copper Line		40	Rinse Water Treatment System
Ni-Au Line			Rinse Water Treatment System
Black Oxide Line			Rinse Water Treatment System

* Not part of Printed Circuit Board Facility

Table II shows the derived rinse water chemistry. It must be noted that sizing to the maximum flow and maximum chemistry, as outlined, can lead to a grossly over-sized treatment system. Obviously, for a set drag-out rate and as the rinse tank flow increases to its maximum, the waste concentrations diminish. On a small system the cost can be explained away as conservative design, but on a large system it would be pure wasted resources. A detailed material balance and a realistic safety factor is required for a truly optimum treatment system.

Table II. Estimated Rinse Water Chemistry

Cations		Anions	
Na	75ppm ($CaCO_3$) →	SO_4	60ppm ($CaCO_3$) →
		NO_3, HCO_3, Cl, F	<6ppm each →
Ca,Cu,Sn,Ni,Cr, Pb	4ppm total	SiO_2, PO_4	
NH_3	2ppm		

Total organic carbon (TOC) = <2ppm of any or all of the following:

Tartaric acid
Formaldehyde
EDTA
Citric acid
Gluconic acid
Thiourea
Glutaric acid

pH = 3 to 6.5

Total suspended Solids(TSS)=unknown

Temperature = 60 - 80°F

The concentration of the organics and complexed metals (primarily copper-ammonium) within the recycle loop were of the utmost concern. Lab scale tests indicated that the organics and metals could be removed. However, the long term results of fouling were still questionable.

Rinse Water Make-up Quality

Fixing the quality of the rinse water make-up was another area to suffer from time constraints. A qualitative approach was used to determine the rinse water make-up quality. It was known from the old facility that the potable water (<80ppm TDS) supply was not pure enough. Several rinse tanks, particulary those around electroless plating baths, required better that two bed deionizers. Particulate levels after sand filtration (≈40 micron removal) were marginal. An acceptable grade water standard was found in ASTM D1193-77 Type III, as shown in Table III.

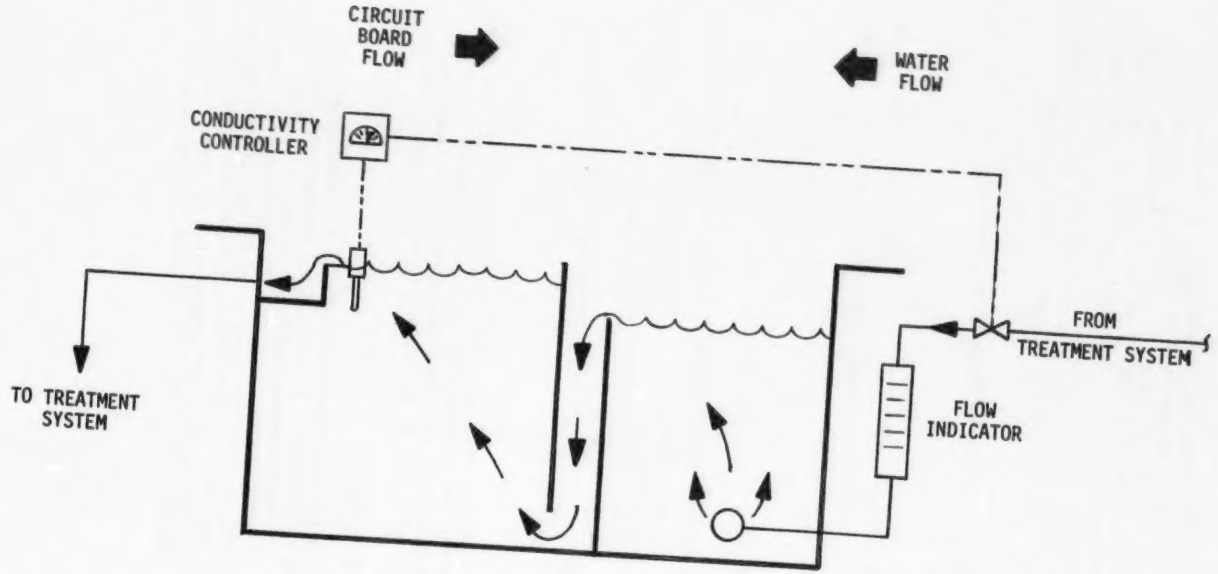

CIRCUIT
BOARD
FLOW
WATER
FLOW
CONDUCTIVITY
CONTROLLER
FROM
TREATMENT SYSTEM
FLOW
INDICATOR
TO TREATMENT
SYSTEM

Fig. 1 TYPICAL RINSE TANK

TABLE III

	Type II	Type III
Total matter, max, mg/litre	0.1	1.0
Electrical conductivity, max, μmho/ cm at 298 K (25°C)	1.0	1.0
Electrical resisitivity, min, MΩ·cm at 298 K (25°C)	1.0	1.0
pH at 298 K (25°C)	[A]	6.2 to 7.5
Minimum color retention time of potassium permanganate, minutes	60	10
Maximum soluble silica	not detectable	10 μg/litre

[A] The measurement of pH in Type II reagent waters is meaningless and has been eliminated from the procedure, electrodes used in this test contaminate the water.

The Type II reagent water specification was adopted after start-up as a goal for the operator. Type II water is specified for laboratory analytical procedures and must be derived from distillation. Type III water is specified for general laboratory testing and can be derived from distillation, ion exchange, reverse osmosis, or a combination thereof, followed by 0.45 micron membrane filtration.

Miscellaneous Criteria

1. Tanks, sumps, controls and treatment system had to be enclosed in an existing 30' x 60' structure.

2. Operation must be 20 hour continuous per day.

3. Methods for predicting ion exchange resin failures.

4. Instrumentation for predicting regenerations.

ALTERNATE DESIGNS

Many alternative designs were evaluated on a brief and subjective basis. Time constraints prevented thorough computation of capital and operating costs. The following summaries of alternate designs are based on the author's personal experience and were not quantitatively derived for the initial design or for this paper. Figure II represents the alternate designs discussed below.

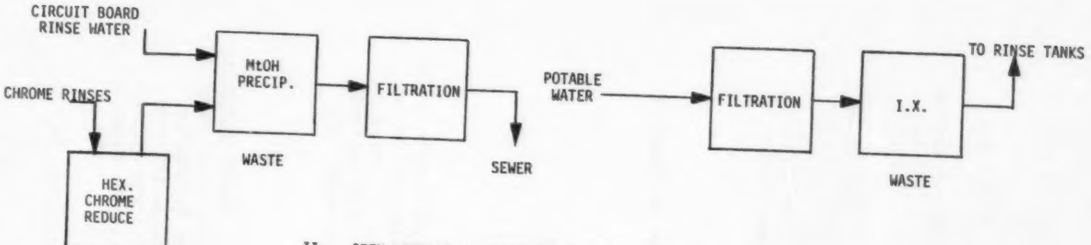
Open Loop Treatment Systems

Hydroxide Precipation of Waste Ion Exchange of Make-up. Metal Hydroxide precipitation is proabley the most common metal finishing rinse water treatment method. The effluent would go the POTW after filtration. Ion exchange would be the most economical method to reduce the relatively low total dissolved solids (TDS) potable water to the desired quality of make-up water. This method was rejected over the final design for the following reasons:

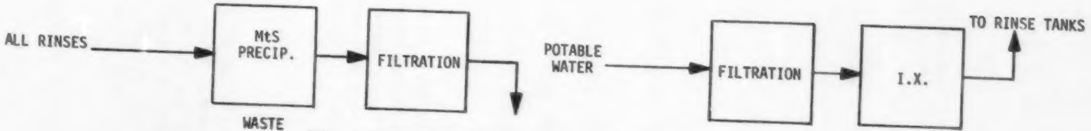
1. Estimated to be at least 1/3 higher equipment cost (not including a larger building).

2. Double the space requirements.

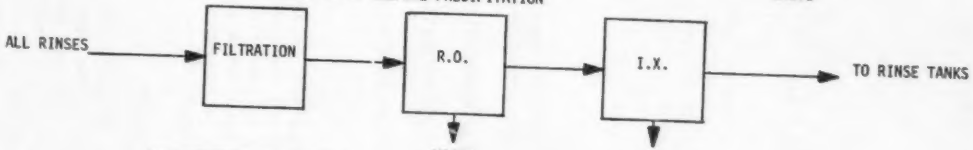
3. Double the operating cost.


CIRCUIT BOARD RINSE WATER
CHROME RINSES
HEX. CHROME REDUCE
MtOH PRECIP.
WASTE
FILTRATION
SEWER
POTABLE WATER
FILTRATION
I.X.
WASTE
TO RINSE TANKS

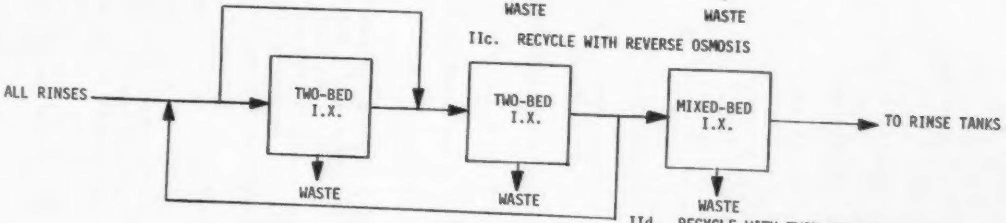
IIa. OPEN LOOP METAL HYDROXIDE PRECIPITATION


ALL RINSES
MtS PRECIP.
WASTE
FILTRATION
POTABLE WATER
FILTRATION
I.X.
WASTE
TO RINSE TANKS

IIb. OPEN LOOP METAL SULFIDE PRECIPITATION


ALL RINSES
FILTRATION
R.O.
WASTE
I.X.
WASTE
TO RINSE TANKS

IIc. RECYCLE WITH REVERSE OSMOSIS


ALL RINSES
TWO-BED I.X.
WASTE
TWO-BED I.X.
WASTE
MIXED-BED I.X.
WASTE
TO RINSE TANKS

IId. RECYCLE WITH TWIN TWO BEDS

FIGURE II. BLOCK DIAGRAMS OF ALTERNATE DESIGNS

4. Would not meet zero discharge of heavy metals.

5. Would not remove hexavalent chrome without a reduction system (see Table I for waste source).

Excessive space requirements are readily apparent. The selected design would be about the same size as just the make-up system in this alternative. Clarifiers (without tube settlers) would operate at one-tenth the hydraulic rate of an ion exchange vessel (10 gpm/ft^2).

Operating costs would include the care of two separate systems. The clarifier would be required to operate at the waste streams worst chemistry. The result would be over feeding of chemicals or a large investment in instrumentation and/or labor.

Items 4 and 5, above, brought the most concern. The mixture of metals indicated in Table II vary in solubilities for any given pH. When operating at a pH to minimize the effluent of one metal, another may be at an high solubility. The result is either non-compliance with the zero-discharge mandate or the increased cost of a two step precipitation system. The sudden and frequent variability of the chemistry and flows raised questions about the sludge blanket stability in the clarifier. Ion exchange of the potable water make-up presented no concerns since such an application is common place.

Sulfide Precipitation and Ion Exchange Make-up. The sulfide precipitation chemistry of heavy metals is well known but little used on large scale, continuous rinse water systems. All of the same concerns are true for this alternative as outlined for the hydroxide system above. The advantages of the sulfide system over hydroxide are lower capital cost, low metal sulfide solubilities and no need for a separate chrome reduction system. Another factor against a sulfide system was poor results from a sulfide system operating at the same company.

Other Open Loop Systems. Reverse osmosis and ion exchange systems were briefly considered for the rinse water treatment stream. Given the effluent discharge requirements, the variable chemistry, variable flows and the high quality water produced from R.O. and I.X., the logical conclusion was to close the loop.

Closed Loop Systems

Reverse Osmosis. Reverse osmosis was briefly considered due to its simplicity relative to regeneration of ion exchange beds. However, precise and consistent rinse water chemistry could not be developed. The presence of sulfates with the metals led to possibilities of metal sulfate precipitates on the membranes. The cost of a full flow back-up system for make-up was prohibitive. An ion exchange polisher probably would have been needed to reach the desired water quality use. While the function of R.O. is straight forward, operation with non-technical, semi-skilled labor did not seem practical. Plant personnel were considerably more familiar with ion exchange systems.

Ion Exchange Systems. Once an ion exchange recycle system was decided upon, several configurations were subjectively evaluated. The most attractive arrangements involved twin two bed ion exchange vessels. That is two cation-anion pairs. The configuration could have been with one pair as a full standby or as a polishing system to the first pair. After exhaustion and regeneration of the first pair, the second would be the primary unit and the freshly regenerated first unit would go into standby or as the polisher to the second pair. Once the second pair is exhausted the first pair becomes the primary and the "merry-go round" continues.

The concept of a full standby was rejected due to limited space, high cost and there was sufficient capacity in one pair to regenerate during non-production time. The double two bed "merry-go-round" system would have made the desired water quality when the two bed systems were in series but not when one was out for regeneration. Another polisher would have been required. At this point it was determined that a mixed bed ion exchange vessel could maintain water quality by itself long enough for a two bed system to regenerate. Therefore, a two bed system with a bypass to a mixed bed vessel was decided upon. The following criteria was achieved:

1. minimum cost
2. minimum space used
3. little impact due to variable chemistries
4. can handle variable flows
5. water quality can be maintained

FILTRATION

Alternatives for pretreatment to the ion exchangers was very straight forward. Particulate and organic removal were prerequisite to ion exchange. A pressure sand filter was selected for particulate removal and a pressure activated carbon filter for organics.

SYSTEM DESIGN

The variability of the circuit board production presented design problems that would not normally be present in a standard, high volume, constant production facility.

The design of the system was primarily controlled by the desire to ensure rinse water quality. Secondary design considerations were economics, ease of operation and flexibility of waste flows. Rinsewater recycle itself naturally fell into place given all the design criteria and a study of the alternative designs.

Flow Scheme

The nature of recycle loops conjours up notions of level and flow controls for balancing and juggling volumes of water. The initial design of this system included electronic flow and level controls. Certainly such controls would be beneficial in standard, constant production facilities.

The need for human judgement in dealing with the various operational modes of this "custom" circuit board facility eliminated the automatic "unthinking" flow controls. Flow controls in the recycle loop are all manual/mechanical components. Figure III schematicly represents the rinse water and waste flows in the circuit board facility.

Normal Flow Condition. As Figure III indicates, all waters to be treated are collected in a common, coated, concrete sump. Since the majority of the rinse tanks are rinsing acid solutions and the fume scrubber is acidic, the flows will be of a low pH. Design should account for a pH as low as 2 and typically between 5.5 and 7. The rinse sump has high and low level alarms and two intermediate level indicating lights. A visual float type level indicator that shows the level at all times was not included but would have helped in the manual adjustment of water levels.

The rinse water in the sump is pumped at a constant maximum rate of 50 gallons per minute (GPM) through the treatment system. The treated water flows to a deionized water storage tank. Since the fume scrubber and a chrome rinse tank contribute up to 10 GPM (80% recycle) from outside the recycle loop, normally the deionized water storage tank will overflow up to 10 GPM into the sewer sump. The overflow is expensive high quality water that should be used elsewhere. The deionized water overflow serves the purpose of a "blowdown" of contaminants that could build up in the recycle loop.

The deionized water is pumped from the storage tank to the rinse tanks. When the solenoid valves in the rinse tanks are closed, a mechanical relief valve opens and the excess deionized water bleeds back to the rinse water sump. The rinse water sump level is manually maintained by one or combination of the following methods:

1. Starve the feed to the rinse tanks thereby causing a deionized water overflow to the sewer in excess of 10 GPM.

2. Pump deionized water direct to the sewer.

3. Add potable water to the rinse water sump.

High Flow Condition. When the circuit board etcher demands an extra 25 GPM, a second (spare) deionized water feed pump is turned on. The deionized water storage tank and rinse water sump are sized for a 50 minute flow at 25 GPM. The volume lost in the storage tank, and gained in the rinse water sump, is balanced by the methods described above.

Abnormal Flow Conditions. The treatment facility has the capability of several abnormal flow modes. Should the treatment system not be able to produce water quality exceeding the potable water, then the following occurs:

1. Potable water is fed to the rinse tanks.

2. Effluent from the rinse tanks are minimized.

3. The waste in the rinse sump is a). treated and sent to the sewer b). hauled away.

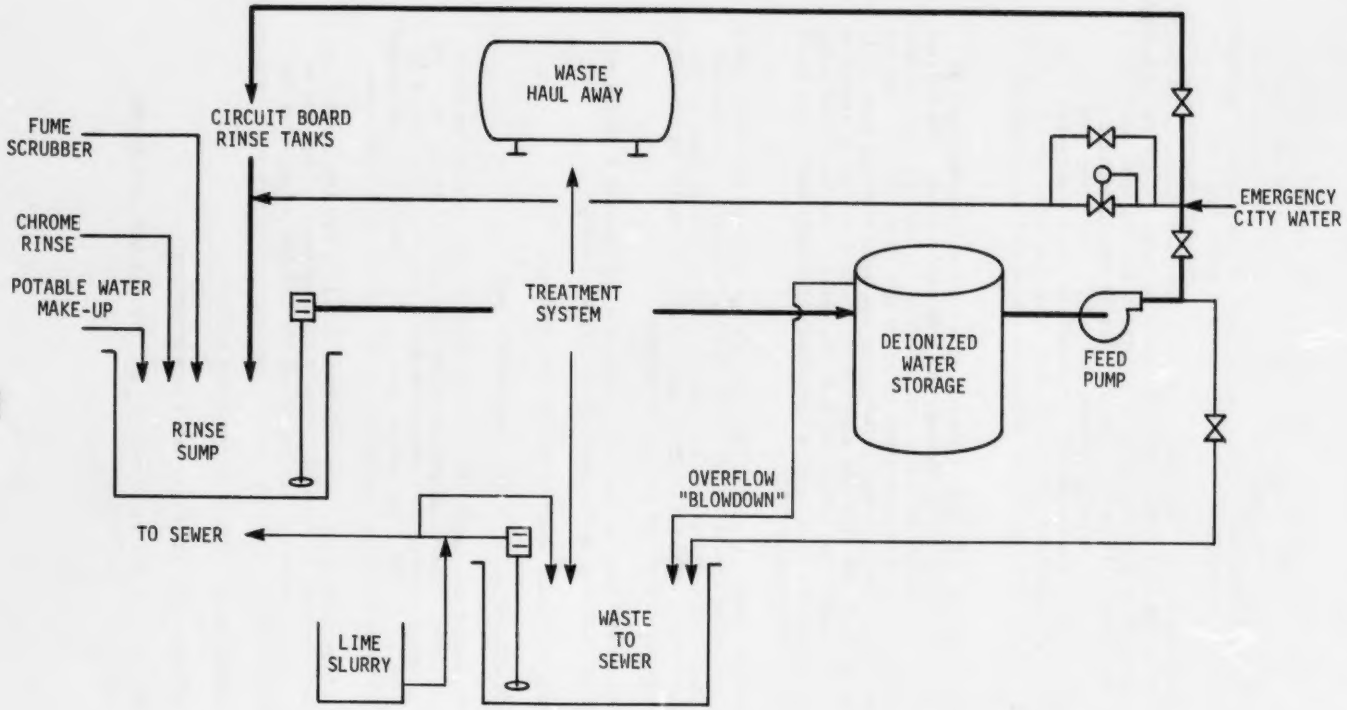

WASTE HAUL AWAY
FUME SCRUBBER
CIRCUIT BOARD RINSE TANKS
CHROME RINSE
POTABLE WATER MAKE-UP
EMERGENCY CITY WATER
TREATMENT SYSTEM
DEIONIZED WATER STORAGE
FEED PUMP
RINSE SUMP
OVERFLOW "BLOWDOWN"
TO SEWER
LIME SLURRY
WASTE TO SEWER

FIG. 3 RINSE WATER FLOW SCHEME

If treatment failure is not catastrophic but slightly off specification, due to a high concentration rinse sump, then the flow to the rinse tanks can be shut-off and the rinse sump recycled to the quality desired out of the treatment system.

FILTERS

Dual Media Filter. The first piece of treatment equipment seen by the rinse water is a conventional downflow pressure sand and anthracite filter. The purpose of the dual media filter is to catch dirt from the caustic clean rinse tanks, metal particulates from the etch rinse tanks and the circuit board etcher. The filtration ability of a dual media filter can be considered to be better than 50 microns for absolute removal. The filter was equipped with bypass valve and piping for use during backwashes. Care should be taken for ensuring proper flow for backwash. In this case 125 GPM of potable water for 10 minutes is required for thorough backwash. Backwash can be initiated automatically by a differential pressure switch or push button at the panel. The filter is sized at 5 GPM/ft^2.

Carbon Filter. The carbon filter is a conventional downflow pressure type like the sand filter. The primary purpose of the carbon filter is to remove organics and particulate removal during sand filter backwash. The sizing of the carbon filter differs from the sand filter since one variable of absorbtion into the carbon media is carbon volume versus surface area for particulate removal. The carbon filter height was maximized for a corresponding maximum volume (61 cu. ft.) of filter grade activated carbon. The specific flow rate is 3 GPM/ft^2. The interior of the pressure filters were coated with a corrosion proof PVC based coating.

Ion Exchangers

Two Bed. The cation-anion vessels are conventional down flow pressure type. The height of the vessels, and therefore the resin heights, were maximized. Due to a lower regeneration efficiency and the presence of weak anionic electrolytes the specific flow rate is lower (5 GPM/ft^2 and 10 GPM/ft^2) and the resin volume higher (44 ft^3 and 22 ft^3) in the anion vessel versus the cation.

Regeneration of the cation and anion resins is accomplished with 5% hydrchloric and 4% caustic as diluted through eductors. Sulfuric acid is not used due to the possibility of metal sulfate precipitated in the resin. At the maximum expected chemistry over a three shift operation, regeneration would occur every 35 hours (105,000 gallons). Strong acid and base macroporous resins were used primarily for their removal of complexed metals.

The cost of regenerating the deionizers was minimized by segregating the regenerant columes. The results was a minimal amount of waste to be hauled away. Potable water was used for backwash and was sent to the sewer sump. All of the acid and caustic regenerant was hauled away. All of the slow rinse and part of the fast rinse went to the sewer. The last part of the fast rinses was sent back to the rinse tank sump. Regeneration of the cation and anion occured simultaneously. During regeneration, the two bed system is bypassed for up to 3 hours. Out of 4000 gallons per regeneration only 800 gallons is hauled away.

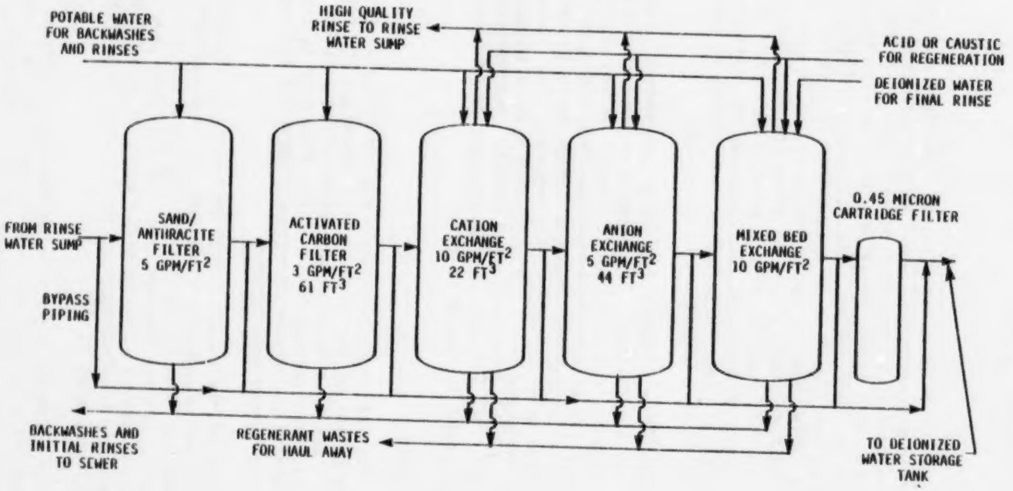

POTABLE WATER FOR BACKWASHES AND RINSES
HIGH QUALITY RINSE TO RINSE WATER SUMP
ACID OR CAUSTIC FOR REGENERATION
DEIONIZED WATER FOR FINAL RINSE
FROM RINSE WATER SUMP
BYPASS PIPING
SAND/ ANTHRACITE FILTER 5 GPM/FT2
ACTIVATED CARBON FILTER 3 GPM/FT2 61 FT3
CATION EXCHANGE 10 GPM/FT2 22 FT3
ANION EXCHANGE 5 GPM/FT2 44 FT3
MIXED BED EXCHANGE 10 GPM/FT2
0.45 MICRON CARTRIDGE FILTER
BACKWASHES AND INITIAL RINSES TO SEWER
REGENERANT WASTES FOR HAUL AWAY
TO DEIONIZED WATER STORAGE TANK

FIG. 4 TREATMENT SYSTEM FLOW DIAGRAM

Mixed Bed. The mixed bed ion exchanger is intended to polish the two bed effluent to the desired quality and to maintain water quality during two bed regeneration. The mixed bed contains 8 ft^3 of cation and 12 ft^3 of anion resin. The mixed bed incorporates into one vessel most of the same regeneration features as the two bed system. Deionized water is used for the final rinse so that processed water quality is maintained. Regeneration, at the worst case, is expected every 250,000 gallons. The regeneration efficiency of a mixed bed is not as good as a two bed system. Hence, contaminant loading in the mixed bed should be minimized. During regeneration the mixed bed is bypassed. Normally, two bed ion exchange can not quite meet the rinse water quality. Off production hours are preferred for mixed bed regeneration.

Instrumentation and Process Control

A combination of in process instrumentation, data recording and laboratory back-up are used to ensure the quality of the rinse waster make-up. Careful design, complete procedures and skilled operators are required.

In Process Instruments. High water purity pH cells and transmitters are located on the effluent of the deionized water tank and each of the two bed and mixed bed ion exchangers. The pH out of an ion exchanger will indicate exhaustion of the resin before conductivity will. This is particulary true where weak electrolytes such as silicia and bicarbonate are found. An entire rinse water system can be contaminated by a concentrated break through of silica prior to detection by conductivity. The use of pH cells designed for high purity water is essential. High or low pH out of the ion exchangers will initiate regeneration and alarms.

Conductivity is measured at the same places as pH. Conductivity functions as a back-up tp pH, to signal the transfer of regeneration rinse waters from the sewer to the rinse water sump and the termination of resin rinses.

Flow indicators and totalizers are required to monitor the efficiency of the resins and the recycle loop. The flow of the potable water, sewer and rinse tank feed are measured. Flow through the treatment system is fixed, therefore, it is not measured. Waste volume to be hauled away is measured by a meter on the disposal truck.

A silca analyzer is placed after the two bed ion exchanger as a predictive tool. Silica is the first continuously measureable ionic species to come off of spent resins that can be measured. The absolute silica measurement is secondary to the characteristic rise in value as the resin is exhausted. This instrument requires high maintenance and is not intended to replace laboratory measurements.

Main Panel. All pH, conductivity and silica measurements are recorded at the panel. The recordings serve as rinse water quality indicators and long term diagnosis of resin performance. The panel displays a 25 point annunciator that indicates the condition of the waste treatment facility, The annunciation displays items such as high or low pH, conductivity, tank levels, silicia and regenerate strengths and bypassed vessels.

All motor switches and running lights are located on the single main panel. A graphic representing the flow paths is included. Miscellaneous switches for double regenerating the anion vessel, bypass any vessel, high flow mode and caustic treatment of the mixed bed.

Electrical control is accomplished by a programmable controller. The single most attractive feature of the programmable controller is the ability to access any step in the regeneration sequences and change items or set points in a very short time. The controller provides lower costs, minimizes space and fragile parts. Above all, the flexibility of adding, subtracting or changing steps is extremely valuable in a process system that has over 60 process sequences involving over 80 valves, 12 pumps, 15 level indicators and 16 process measurements.

Laboratory Back-up. Final rinse water quality assurance is provided by a fully equipped laboratory. A lab with a total organic carbon analyzer, atomic adsorption and calibrated pH and conductivity instruments is required. The laboratory is responsible for the following tasks on a set time table:

1. Calibration of process instrumentation

2. Measurement of trace organics

3. Measurements of influent, intermediate and effluent process water quality

4. Ensure compliance with regulatory waste discharge requirements

Common Miscellaneous Design Items. There are a number of small design features that make the treatment system easier to operate within the water quality specifications. A few of these features are:

1. Access to all sides of each pressure vessel.

2. Vessel manholes on the open, back side shell of the tanks.

3. Vessel connections for easy resin sampling.

4. Water sample valves in each vessel.

5. Solenoid valves with manual operators in case of automatic failure.

6. All main valves, solenoid valves and air tubing are numbered.

7. Adequate floor drains and trenches to contain leaks and wash downs.

8. Sink and work space for handling samples and equipment.

9. Readily available anti-fouling chemicals as specified by the resin supplier or through research.

10. The treatment equipment can be procured pre-assembled and skid mounted.

All ion exchange systems that involve hauling away the waste acid and caustic regenerates should investigate further volume reduction of the 4-8% solution. Chemical precipitation and evaportation were studied for this facility. Chemical precipitation on this small scale would be labor intensive and would not reduce waste volume enough to warrant the capital expenditure. Additionaly, the solid product would not be compatiable with the hauling of the remaining liquids from the manufacturing facility. An evaporator would be economical if there was an existing source of low pressure steam and a single point for condensor heat recovery. The evaporator could concentrate up tp 40% solids but economical steam and heat recovery were not available.

OPERATION

The printed circuit board manufacturing facility has been in operation for a little over one year. Since the beginning of this year the facility has been continuing process qualification work and limited production runs at the rate of 200 boards per day, over two shifts. The beginning of next year you will see 1000 boards per day over three shifts. This manufacturing facility handles custom boards and short production runs.

Water Chemistries

Operating data indicates that waste rinse water is reading a conductance of 102 μmho/cm. This translates to 60 parts per million (ppm) TDS as sodium sulfate for a production rate of 100 boards per shift. Therefore, the maximum rate of 1000 boards per day, or 333 boards per shift, the expected concentration would be 200 ppm TDS, since the flow rate is fixed. The derived TDS for design (Table II) was 160 ppm. It appears the predicted loading to the ion exchangers was 20% short. The result at full production will be a 20% shorter run time (28 hours instead of 35) between regenerations. More detailed analysis of the waste stream is not available at this time.

A pleasant surprise is no indication of organics in the rinse water, let alone in the make-up water. There are two potential explanations for these measurements. They are 1). The 2ppm TOC measured in the old facility may have been due to biological growths or oils in the system or the samples and 2). the lower limit for the TOC analyzer is 0.1ppm and the current low production rate is not high enough to meet the analyzer's lower limit. Based on an order of magnitude analysis, the authors tend to believe the second explanation. Organic levels in process solutions seldom exceed 0.1% and say dissolved solids are around 6%. Therefore the dilution factor of 6% to 60ppm is about 1000. The dilution of the organics by 1000 would be less than 1ppm. It is probable the organics will be measureable when production increases.

Processed water has consistently exceeded the ASTM D1193-77 Type III specification for reagant grade water. During mixed bed regeneration (3 hours duration every 56 hours at full production) the two bed can not meet Type III water. The entire system can meet Type II water but occasionaly exceeds the silicia limit. It appears no circuit board manufacturing problems are traceable to the rinse water quality.

Flow Controls and Volumes

The control of the water volumes within the recycle loop were in fact a matter of judgement and skill acquired by the operator. The high flow rate option for the board etcher has not been used to date. The operator chooses to maintain the rinse water sump level by using the manual rinse tank bypass route to the rinse water sump. This essentially fills the feed sump with product water and minimizes the overflow from the deionized water storage tank. The operator also uses this mode to dilute the rinse water sump when the sump pH drops to 5.5. It was noticed the water quality drasticly deteriorates when the pH drops below 5.5. It is probably due to "regeneration" of the carbon filter or the cation resin.

Table IV summarizes the liquid volumes treated, recycled, sewered and hauled away. Remember, the liquid volumes are directly proportional to the TDS level in the waste rinse water. If a proportional method is used, to predict system performance, it assumes all rinse water constituents are also changing by the same proportion. The two bed system was regenerated approximately every 300,000 gallons and the mixed bed at every other two bed regeneration.

Operating Problems

Several operating problems have surfaced over the year the treatment system has been operating. The largest problem is possible iron fouling of the cation resin. The condition was diagnosised via a resin analysis by a non-resin supplier. A cleaning chemical was supplied by the resin analyzer and negligible results were obtained. Two sources of iron are suspected - the city water used for backwash and rinses and an experimental ferric chloride bath. Resin suppliers and previous experience indicates that an higher regenerant strength (approx. 7%) may be required.

Other recycle systems at the same company have had problems with too clean of a rinse water. Some parts have trapped high resistance water and hindered the subsequent electro-chemical process. Treatment system bypass can regulate the "dirtiness" of the rinse water.

Particulates did pose a problem for the discharge to sewer. Small levels of copper and chrome were found in the discharge to sewer after filter backwashes. The filters are backwashed three times a week to minimize metal concentrations.

Economics

Real operating costs for this system, to date, are meaningless due to the production rates and variability of this circuit board facility. The designer is encouraged to extrapolote and apply their own operating cost figures to the data supplied in Table IV. Capital costs can be more realisticly estimated by cost indexes. The costs for treatment equipment, enclosed facility and installation labor were approximately $300,000, $150,000 respectively in 1979 dollars.

TABLE IV TREATMENT SYSTEM PERFORMANCE

TIME	Waste Quality (umho/um)	Production Rate (Boards/shift)	Deionized Water Produced (Gal)	Potable[A] Water Water Used (Gal)	System[B] Make-up Water (Gals)	Recycle %	Waste[C] Hauled Away (Gal)	HCL Consumed (Gal)	NaOH Consumed (Gal)
Jan-Apr	102 (ave.)	100	2,310,000	155,000	250,738	89	27,750	350	935
May-Aug.12	102 (ave.)	100	2,807,000	196,000	128,000	95	----	--	--

[A] City water used exclusively for backwashes and rinses. High quality rinses are sent back to the rinse water sump.

[B] City water make-up into rinse water sump to account for overflow of deionized water tank.

[C] A very small and unknown part of this volume is discarded process solutions, floor wash down, etc.

SUMMARY

The recycle of printed circuit board manufacturing rinse waters was not required until the recent demand for discharge limitations and high quality make-up water. The degree of success for metal finishing rinse waters is dependent in the following points:

1. Knowledge of the waste water and rinse water chemistries.
2. Characteristics of the waste and feed flows.
3. Facility waste discharge limits.
4. Proper capital and operating cost application of unit treatment processes.
5. Adequate process monitors, laboratory back-up and predictive procedures.

Full attention to the items outlined above, can help achieve better than 90% recycle rates, and minimize capital and operating costs.

Acknowledgements

Bart Dinwiddie for ignoring the drawings and building a workable system and then operating it even better.

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PB82-223595

COST-EFFECTIVE LAUNDRY WASHWATER RECYCLE

Roy A. Ackerman, P.Ch.E.
Technical Director

Samuel C. Crosby, I.D.S.A.
Principal Engineer

C. Paula Inigo
Engineering Associate

ASTRE Corporate Group
920 Harris Street, P.O. Box 5072
Charlottesville, VA 22905

INTRODUCTION

With ever increasing prices to be paid for energy and water, many laundry owners are implementing programs to minimize water and energy waste. Recognizing that the average laundramat uses something on the order of 100 gallons per wash, with 12 washers, a weekly water demand on the order of 70,000 gallons is not out of the question. Pretreatment costs in conjunction with the loss of heat in the effluent water force the laundry owners to recycle.

There have been several systems developed to recycle laundry wastewater, ranging from chemically-based systems to membrane-based systems. Much of the design work has been aimed at military installations, such as army bases and navy ships (1,2). There is also one commercial system aimed at the hospital and commercial laundry market(3).

One of the drawbacks to all of these systems is that they are too complicated to allow the average laundry manager to service and maintain the units. To satisfy the needs of the commercial laundramat, a system that would meet the criteria shown in Tables 1 and 2 was designed.

One immediately notes that a total recycle package was eliminated at the outset because of the varied water demand at commercial laundries. To accommodate a 100% reuse situation, very large equalization and/or storage facilities would be required. By handling only 75% of the projected 15 gallon per minute flow rate (based upon the 12 washer commercial laundramat), one could accommodate the widely fluctuating hydraulic loads in a commercial laundry.

The skid-mounted unit is easily installed and reduces the installation costs. Commercial laundry owners do not want to spend more than 15 minutes daily servicing this device. An occasional filter cleaning or an automatic backwash accommodation would be acceptable, but extensive manipulations with chemicals or adjusting valves and settings would not be tolerated. In addition, the operational costs for this system could not exceed 13¢ per cubic meter. This obviated the use of copious quantities of chemicals and/or expendable devices.

Based upon the product development and water quality criteria (Tables 1 and 2), the minimum system required the use of mixed media filter, in conjunction with activated carbon and either ion exchange or reverse osmosis. It was hoped that the mixed media filter would remove suspended particles, reduce the turbidity, and perhaps, in conjunction with a flocculant, remove and/or reduce phosphates and hardness from the water.

The activated carbon column would serve manifold purposes. Organics from dirty clothes and detergent builders would be removed, as well as the hydrogen sulfide that developed during water passage through the mixed media filter.

Furthermore, bleach that may be added in the wash would, of course, be removed by the activated carbon. It is a well known fact that free chlorine and many forms of combined chlorine are readily removed by activated carbon. On the order of 3 to 4 grams of free chlorine and almost 1 gram of combined chlorine can be removed per gram of activated carbon. As such, the activated carbon would render the processed water virtually organic- and suspended solids-free.

The functionality of the ion exchange system would be to remove ions, but it was not necessary that the final product water be ion-free. Product water containing 500 to 1500 mg/L of dissolved solids would certainly be satisfactory. Therefore, weekly or monthly ion exchange regenerations would be necessary (which is analagous to the frequency of activated carbon system replacement).

It is entirely possible that the ion exchange system could even be a self regenerating unit. The mixed media filter would automatically backwash when the pressure differential exceeded 10 psi. The activated carbon would be discarded and not regenerated, since there was insufficient carbon usage to merit same.

PROCESS DESIGN

Mixed Media Filter

Initially it was thought that a mixed media filter alone might remove turbidity and suspended solids from the washwater. Pilot evaluations were effected to determine if a single or a dual stage mixed media filter would provide the desired results, as shown in Table 3.

This proved not to be the case. The turbidity was excessive and there was virtually no change in any of the other parameters due to the mixed media treatment. Furthermore, there was no significant difference between the single mixed media and the or two mixed media filters in series.

As such, it was determined that a flocculant would be necessary to assist the operation of the mixed media filter. After evaluating the 14 flocculants on a pilot bed/jar test basis, it became obvious that two of the flocculants would provide the best results. These flocculants were then tested in a continuous single mixed media filter run. As shown in Table 4, the 1C flocculant was capable of reducing the turbidity to the levels desired, but had very little affect on the total dissolved solids or phosphates. In addition, the color removal effected by 4C was far superior to that achieved by 1C or any of the other flocculants.

This is not surprising because this flocculant is known for its capability to remove colors resulting from the dyeing and bleaching of fabrics. The flocculant is resistant to chlorine and is a replacement for alum and iron coagulation (producing less sludge than the compounds it replaces). As such, all further testing was then effected utilizing the 0.4 ml/L (0.45 mg/L) dosage of 4C (pilot data not shown).

Activated Carbon

The activated carbon tests included both isotherm (equilibrium) and pilot evaluations. The isotherm data, however, was inconclusive. (The isotherm tests demonstrated that a range of 0.2 to 0.5 grams of carbon per 100 ml of laundry wastewater would be sufficient.) The only conclusive data from the isotherm studies was the effect of activated carbon on the level of phosphates in the effluent. It became obvious that the activated carbon donated phosphates to the water.

To prove this was not an artifact, isotherm tests were performed using activated carbon with phosphate- free detergent and with or without bleach. Figure 1 demonstrates the average of some 20 isotherm tests. With no activated carbon, there was no phosphate in the effluent. As the activated carbon dosage increased, significant phosphate levels were found. As such, it became obvious that the ion exchange system (if used) would not only have to treat the phosphates provided by a detergent, but also those leached out of the activated carbon.

Pilot columns were evaluated with flow rates of 0.08 m/min (2 gpm/sq. ft.) through the carbon columns. The pilot studies demonstrated that a nominal detention time of 20 minutes would be sufficient to remove detergents, COD, as well as chlorine.

Ion Exchange

The ion exchange system was employed to limit the total dissolved solids to 1500 mg/L and remove phosphates from the washwater. (The pilot studies had already indicated that hardness would be removed sufficiently via the use of a flocculant in conjunction with the mixed media filter.) As such, an anion exchange resin operating on the hydroxide cycle was chosen.

The isotherm tests showed that 0.15 grams of ion exchange resins would be more than sufficient to treat a liter of wastewater. Pilot facilities using continuous flow techniques demonstrated that at a flow rate of 0.08 m/min (2 gpm/sq. ft.) and a 10 minute detention time, virtually all of the phosphates would be removed from the system.

Full Scale Trials

Based upon the pilot analysis, the system chosen included a mixed media filter (containing plastic beads, anthracite coal, and silica sand), an activated carbon column, and an anionic exchange resin bed. The exit water was on the order of pH 8, which would not create any major problems. As a matter of fact, such a pH may lessen the need for the detergent.

The system was designed for weekly regeneration of the ion exchanger and monthly replacement of the activated carbon. In addition, whenever a 10 psi differential pressure across a column developed, a backwash would be automatically effected.

The system configuration is shown in Figure 2. The washers emptied into an equalization basin. (It must be remembered that mixed media filters, carbon filters, and ion exchangers are derivative-type processes, and as such, average flow conditions are desired for such systems.) The average commercial laundry use 190 to 265 cubic meters (50,000 to 70,000 gallons) per week during 85 hours of operation, for an average flow of 0.95 L/s (15 gpm). With peak flows of 6.3 L/s (100 gpm), the equalization basin required 6.5 cubic meters (1700 gallons), yielding a peak equalization detention time of 20 minutes. The equalization tank was not skid-mounted. Rather each laundry will use a customized equalization tank to accommodate variations and yet still employ the same process system.

The pump, sized at 0.95 L/s (15 gpm) forced the water through a cartridge filter whose main function was to remove lint and gross particulate solids. The flocculant was then mixed with the cartridge filter effluent at the rate of 0.4 ml/L (0.45 mg/L). The mixed media filter was designed to treat 0.08 m/s (2 gpm/sq. ft.) flows (1 m of media depth). The activated carbon filter was an unflow column, with a 20 minute nominal detention time initially (0.08 m/s). The upflow ion exchange system, 0.08 m/s nominal flow rate and a ten minute detention time, followed. The upflow versions were chosen to minimize the pressure drop through the system and the pumping costs.

It is obvious therefore, that the major suspended solids removal function was to be effected by the mixed media filter. However, carbon dust, which was continuously discharged from the carbon filter, was removed in the upflow the ion exchange column.

The storage tank, shown in Figure 2 as F, contained 3.4 cubic meters (900 gallons). At the intersection shown to the right of unit F is a flow control valve. Flows in excess of 0.75 L/s (12 gpm) were discharged to drain. As such, the treated storage capacity contained at least one hour's capacity. This tank was also not skid-mounted.

This system was installed in a laundramat that was not yet patronized or commercial. Sample tests were effected in the various washers to insure the fact that the water quality was sufficient to meet the desired criteria. Over the course of 30 days of testing, it became obvious from testing the bacterial levels of the clothes that excessive levels of bacteria were present. As a matter of fact, it was found that bacteria could be transfered from the dirty laundry to the clean "test" washes.

At that point, various microbial tests were effected on non-recycled laundry water. These tests confirmed suspicions that the bacteria were present already on the soiled clothes and would be transferred to other clothes in the wash- whether or not the water was recycled or fresh water. This phenomena has also been observed by Walter & Schillinger (4) and Buford et. al. (5). As such, fears attenuated and the laundramat testing continued.

Total plate counts were effected on all effluent wastewaters, in particular in the storage tank and also in the ion exchange effluent (E). At no time did the total plate count in either the effluent or the storage tank exceed the quality criteria desired, which was 100 microorganisms per ml (48 hour standard plate count). Turbidity never exceeded 5 JTU, and the total hardness, phosphates, total dissolved solids, total nitrogen, pH, suspended solids and chlorides also did not exceed the requirements.

The major failure was the COD (requirements of 50 mg/L). As seen in the accompanying figures (3 and 4), the COD often exceeded 100 mg/L (but never 200 mg/L). While this value did exceed the originial quality criteria, studies demonstrated the laundry quality and the cleanliness were not affected by this excessive COD. However, in an attempt to reduce the COD levels to well under 100 mg/L, a 30 minute detention time was chosen for the carbon bed.

Further testing demonstrated that backwashing automatically at 10 psi differential pressure did yield satisfactory performance. Hydrogen sulfide odors were produced in the effluents of the mixed media filter. In addition, backwashing of the mixed media filter became difficult if it was not effected other thank solely at 10 psi differential pressure. As such, an automatic timer was used, in addition to the differential pressure mechanism to effect filter backwashing. If the 10 psi differential pressure was not met in any given day, when the flow was terminated for more than 2 hours, the media filter was automatically backwashed. The two 2 hour delay time was necessary because of the possibility that there may be no water demand for a given period of time, but a two hour differential time lag would insure that the "no-flow" condition was due to the daily closing of the laundramat.

The only operational costs required by this system include the replacement of the cartridge filter, the use of the flocculant, replacement of the activated carbon media, and regeneration of the ion exchange resin. Three cartridge filters were required per month at a cost of $6.00. In addition, the activated carbon bed had to be replaced every month at a cost of $49.00 (bimonthly for the thirty minute bed). The ion exchange costs were about $10.00 per month for regeneration. The flocculant costs were about $20.00 per month. The sum, in conjunction with electricity and maintenance costs, came to less than $150.00 per month. This is less than 13¢ per cubic meter (49¢/kgal), which was the goal. The daily service time required came to far less than the 15 minutes, averaging about 5 minutes per day of operation.

Returns on investment were not calculated because the sewage and organic charges are a function of the city in which the unit is located. However, the maximum capital costs for this system are predicted to be $15,200 including profit for the manufacturer. As such, the system has a two year payback period, when sewer and water charges are included in the analysis.

CONCLUSIONS

Over all then, we see that while the COD values did exceed the desired aim, it is entirely possible that the criteria were unnecessarily low. No deterioration in the textile characteristics or cleanliness were observed as a result of the higher COD levels . The water quality as originally espoused have been modified. Further testing is being effected to determine the maximum COD levels that maintain adequate laundry characteristics.

It is, therefore, expected that we could maintain the costs of 13¢ per cubic meter. This system is skid-mounted (with the exception of the storage and equalization tanks), having minimal equalization and storage capacity. The total installed cost is less than $16,000. Hydraulic capacity is 0.95 liters per second, at 75% reuse.

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3. Claunch, RW, "Redux Water Recycling System", Water Reuse- From Research to Application, Volume 1, pp. 433-447 (1979).

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Table 1

DEVELOPMENT CRITERIA

MUSTS

1. WATER QUALITY ACCEPTABLE FOR INTENDED USE
2. SYSTEM CAPACITY OF 0.95 l/s (15 gpm) AT 75% REUSE
3. SKID MOUNTED SYSTEM
4. OPERATIONAL COSTS LESS THAN $0.13/cu m ($.50/kgal)
5. 15 MINUTE DAILY SERVICE TIME (max)
6. MINIMAL EQUALIZATION & STORAGE CAPACITY
7. ROI OF 15% INCLUDING INSTALLATION COSTS

WANTS

1. SYSTEM COMPRISED OF STOCK COMPONENTS EXCLUDING FRAME &SUPPORTS
2. EFFLUENT DOES NOT NEED EXTRAORDINARY HANDLING OR DISPOSAL
3. SYSTEM SMALLER THAN 1.2 x 6 m (4 x 8 ft)
4. PATENTABLE SYSTEM

Table 2

QUALITY CRITERIA

ODOR	**not unpleasant**
TURBIDITY	**5 units**
TDS	**1500 mg/l**
TOTAL HARDNESS	**200 mg/l**
DETERGENTS	**1 mg/l**
COD	**50 mg/l**
TOTAL NITROGEN	**50 mg/l**
pH	**5 - 8.6**
SUSPENDED SOLIDS	**10 mg/l**
CHLORIDES	**400 mg/l**
TOTAL PLATE COUNT	**100/ml**

Table 3

SUMMARY OF PILOT FILTER EVALUATIONS

Test Type	Time, min	Turbidity JTU	TDS, mg/L	Hardness mg/L	Alkalinity mg/L	Detergents mg/L
Single filter	0	151	450	58	1350	1.21
Avg. flow =	5*	80*	300	43	1000	0.3
0.84 L/m^2-s	10	110	390	61	1450	0.6
(1.23 gpm/ft^2)	20	187	600	60	1500	1.16
	30	163	475	60	1400	1.36
	45	155	460	57	1550	0.97
	60	198	460	61	1600	0.96
	90	203	490	61	1450	1.04
	105	260	500	60	1500	0.96
Dual filter into stage 1	0	65	400	50	1200	60
into stage 2	0	58	325	64	1000	58
Avg. flow =	5	58	310	56	1000	56
1.82 L/m^2-s	10	51	325	56	950	58
(2.66 gpm/ft^2)	20	51	310	52	1050	56
	30	49	305	50	1150	52

*still had residual backwash water in the filter

Note: TDS = total dissolved solids

Table 4

SUMMARY OF PILOT FILTER EVALUATIONS

Test Type	Time, min	Turbidity JTU	TDS, mg/L	Phosphates mg/L
Single filter 0.6$\frac{ml}{L}$ "1C"	0	173	500	248
	10	28	230	248
Avg. flow =	20	29	400	248
1.11 L/m^2-s	30	29	450	248
(1.62 gpm/ft^2)	45	42	425	248
	60	51	375	248
	90	56	350	248
Single filter 0.1$\frac{ml}{L}$ "1C"	0	85	350	120
	10	14	340	110
Avg. flow =	20	5	340	110
1.92 L/m^2-s	30	5	340	110
(2.80 gpm/ft^2)	45	5	340	110
Single filter 0.3$\frac{ml}{L}$ "4C"	0	95	600	241
Avg. flow =	10	3	450	190
1.77 L/m^2-s	20	1	550	190
(2.58 gpm/ft^2)	30	1	600	190
	45	1	600	190

Note: TDS = total dissolved solids

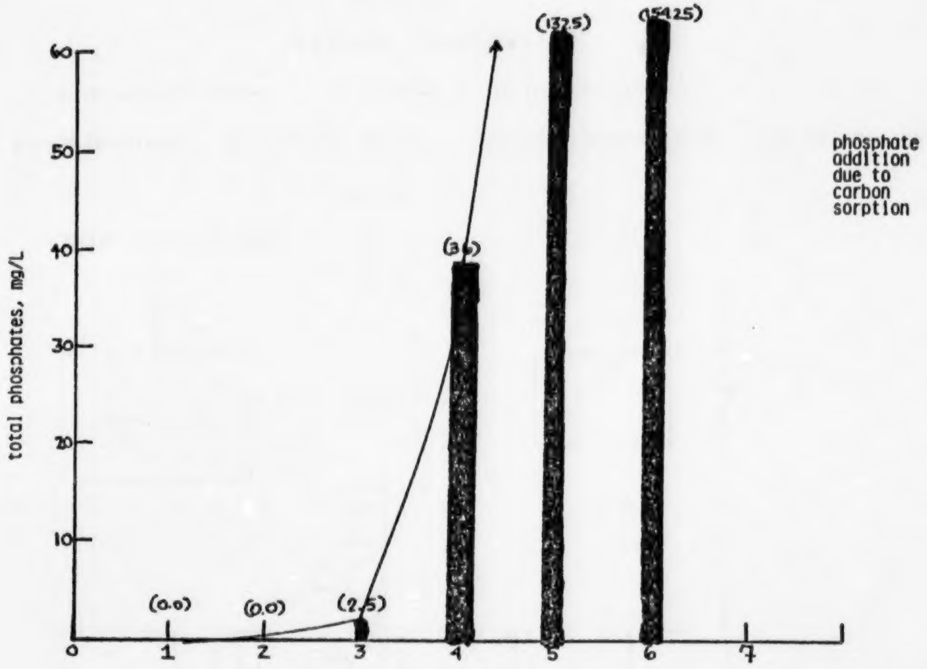
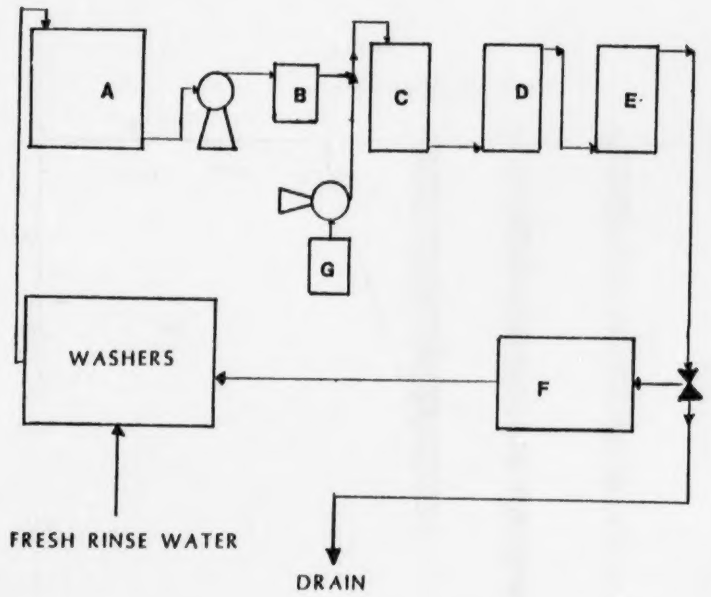

total phosphates, mg/L
60
50
40
30
20
10
0
1
2
3
4
5
6
7
(0.0)
(0.0)
(2.5)
(36)
(137.5)
(15425)
activated carbon, g/L
phosphate
addition
due to
carbon
sorption

Figure 1


A
B
C
D
E
G
WASHERS
F
FRESH RINSE WATER
DRAIN

A-equalization B-cartridge filter C-mixed media filter D-carbon filter
E-anion exchanger F-storage G-flocculant tank

SYSTEM SCHEMATIC

Figure 2

COD EFFLUENT VALUES

CARBON DETENTION TIME OF 20 min

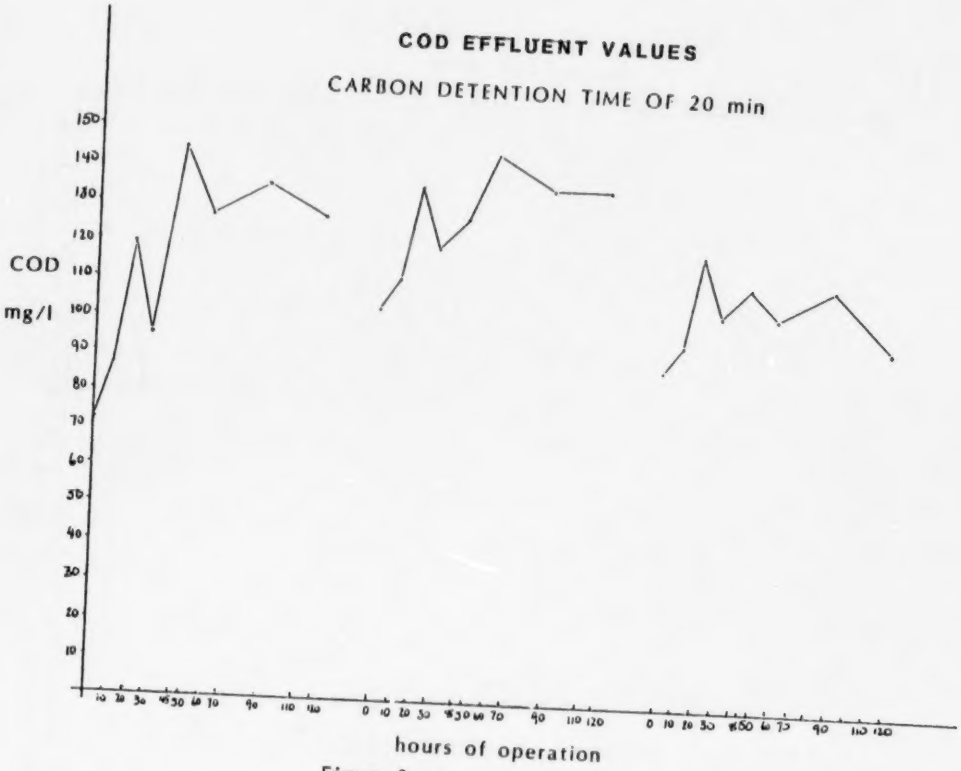
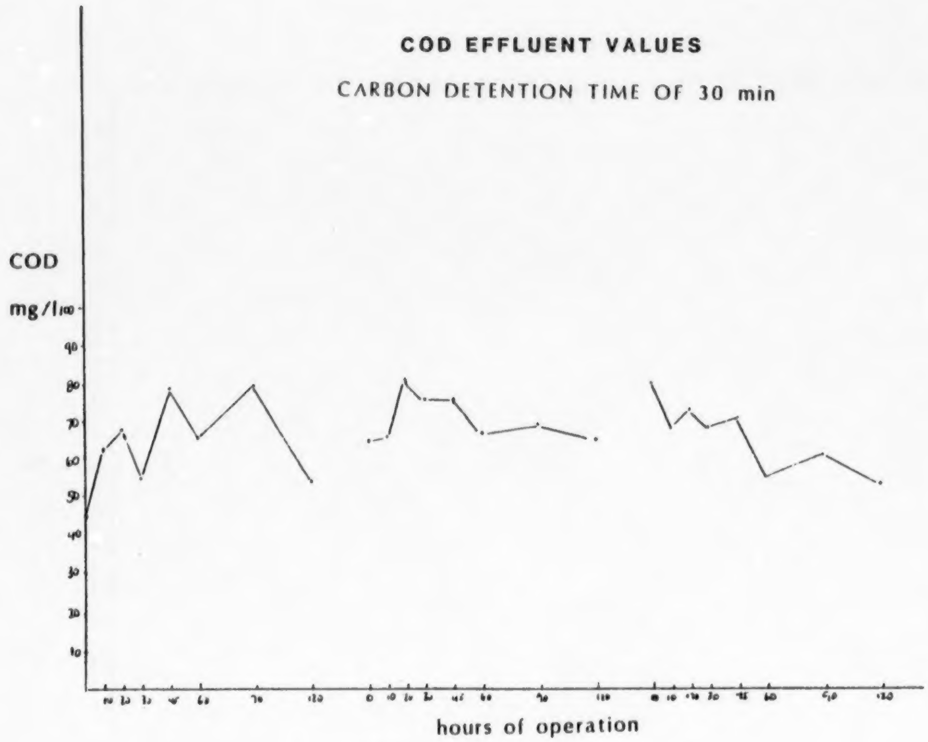


Figure 3



COD EFFLUENT VALUES

CARBON DETENTION TIME OF 30 min

Figure 4

PB82-223603

RUNOFF FROM UTILITY WASTE LANDFILL TO BE RECYCLED FROM DETENTION BASIN TO SCRUBBER MAKE-UP

John J. Lentz, Ph.D, P.E.
Senior Staff
The Johns Hopkins University Applied Physics Laboratory
Johns Hopkins Road
Laurel, Maryland 20707

PERSPECTIVE

Run-off from the working face of a proposed landfill for blended fly ash and scrubber sludge at the Vienna, Maryland plant of Delmarva Power and Light Co. (DPL) will be captured in a lined retention basin and used for seven-to-ten percent of total scrubber make-up needs in order to prevent escape of heavy metals and high total dissolved solids (TDS), mostly calcium and sulphate ions, into the sensitive surface water and ground water of Maryland's portion of the Delmarva peninsula. The high mineral content of the run-off is not expected to interfere with scrubber operation (1).

The effectiveness of this concept depends on how well basin capacity and scrubber make-up pumping rates are matched to both scrubber make-up needs and the rate at which runoff is generated by precipitation. An investigation of DPL's proffered scheme for matching these parameters was made for the Maryland Power Plant Siting Program (PPSP) by The Johns Hopkins University Applied Physics Laboratory (JHU/APL) as part of a broader study of the potential environmental impact of a proposed 600 MW(e) plant expansion at the Vienna site. The study of the effectiveness of the runoff detention basin employed thirty years of daily temperature and precipitation data to simulate continuing operation of the basin and make-up system under a variety of assumptions and alternate operating rules. This paper discusses the results of that analysis within the larger context of the total plant site evaluation (2).

Overall Waste Disposal Planning

When the Delmarva Power and Light Company (DPL) proposed a 600 MW(e) scrubber-equipped coal-fired expansion for its Vienna, Maryland generating station, regulatory concern focused on site conditions which included compressible clays, a vulnerable shallow water table aquifer which regularly rises to ground surface, and important terrestrial and aquatic resources. Responding to these concerns, DPL substituted for its original waste disposal plan a revised plan centered on the isolation of unfixed but plastic waste. The earlier plan had envisioned the fixation of waste with lime, but studies had shown that such wastes would be relatively brittle and subject to cracking and leaching.

Because such brittle utility wastes fixed with lime could be expected to crack following differential settlement over variable deposits of compressible clay, the waste pile would then acquire a high bulk permeability which would in turn permit contamination of the underlying high quality water table aquifer by leachate. Finite element modeling showed that flyash and scrubber sludge, unfixed but blended, would not become saturated during a three-year placement period while being piled in individual cells 40 feet (12.2 m) high. Utilizing the results of these studies, current plans call for the wastes to be placed 40 feet (12.2 m) high in ten 16.5-acre (6.7 hectare) cells each requiring three years to complete. To maintain post-settlement separation of the pile from a water table reaching to ground surface the waste will be placed on a base layer of gravel five feet (1.5 m) thick. Ambient precipitation will be excluded by covering each cell with an impermeable cap, such as an artificial membrane, which will itself be protected by a vegetated cover layer.

Economic evaluation by DPL has shown the use of the gravel fill and membrane cover will be no more costly than the fixation initially planned.

Use of a Detention Basin to Prevent Contamination by Landfill Runoff

Because high concentrations of TDS and heavy metals were expected in any leachate to ground water, it was also feared that similar contamination would occur in runoff from the uncovered surface of any active landfill cell. To prevent the discharge of contaminated runoff, DPL proposes to capture runoff in a basin with 11.4 acre-feet (14,063 m^3) of capacity, lined to prevent ground water contamination, for recycling to scrubber make-up at a rate of 40 gallons (0.15 m^3) per minute (gpm). DPL agreed in separate stipulations to prevent overflow "except under conditions more extreme than a 10-year 24-hour rainfall event" and to maintain one foot of freeboard at that time (3,4). For Dorchester County, Maryland, the site of the plant, the 10-year, 24-hour rainfall is 5.4 inches (13.7 cm) (5). When overflow occurs, discharge from the basin will go to natural drainage, where it might have an impact on both ground water and surface water if concentrations after dilution in the ambient environment exceed toxic levels. The analysis made to test the adequacy of the basin design is described below.

The Maryland Power Plant Siting Program

PPSP was established in 1971 to ensure that timely and cost-effective response to expected demand for electric power in Maryland could be achieved without damage to the environment. The Program evaluates the sites of proposed new generating stations, monitors existing generating sites, evaluates and purchases sites that can be made available to utilities, and sponsors research into environmentally related topics. Before a Certificate of Public Convenience and Necessity may be granted by the Maryland Public Service Commission (PSC), environmental impact must be considered at extended public hearings and found acceptable. PPSP provides the mechanism for an integrated involvement of all agencies of the State government in that process. All of these activities are supported by a surcharge, presently 0.11 mills per kilowatt-hour, on electricity generated within the State.

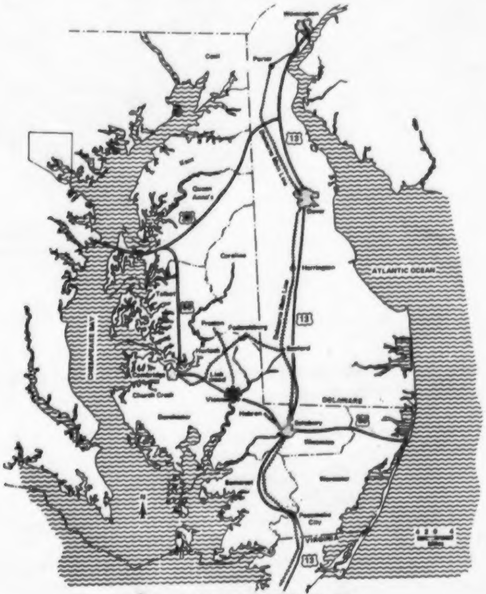
The Johns Hopkins University Applied Physics Laboratory assists PPSP in its review of proposed new plants: it reviews applicant submittals, carries out or supervises additional studies, prepares reports, and offers testimony at the public hearings of the PSC.

For the proposed Vienna expansion, PPSP and JHU/APL undertook to work with DPL and its consultants to resolve concerns over the unique conditions at Vienna. Besides the solid waste disposal issue, of which the runoff collection and recycling basin will be a part, other concerns included impact on a striped bass spawning ground, noise emissions, sociological impacts, and the probable effect of cooling tower fogging and icing on a new elevated highway planned to bisect the site. These topics are described in detail in individual reports to the PPSP and in the summarizing Overview report, all of which were entered into evidence at the public hearing (6,7).

PRELIMINARY ENVIRONMENTAL ASSESSMENT

The proposed 600 MW(e) expansion is designated Unit 9 and is planned to become operational in 1987. Units 1 through 7 have already been retired from service. Unit 8, a 155 MW(e) oil-fired unit, will continue in its current service as a peaking unit.

The Vienna site is located on the Delmarva peninsula where U.S. 50 crosses the Nanticoke River. See Figure 1. The terrain is flat, elevation is low, drainage is westward toward the Chesapeake Bay, and the Nanticoke River is estuarine and sometimes brackish at this point. The locality is rural and agricultural; no more than 600 people reside within one mile (1.6 Km) of the plant site.



✱ LOCATION OF VIENNA SITE

Figure 1

Assuming operation for 6,000 hours each year, Unit 9 will generate 630 tons (572 tonnes) of fly ash and 1200 tons (1089 tonnes) of scrubber sludge (20 percent moisture content) for an average waste volume of two-thirds of an acre-foot (822 m^3) per day. The limestone scrubber will produce thixotropic calcium sulfite hemihydrate which will then be oxidized to produce the physically more stable calcium sulfate dihydrate, "abatement gypsum". The scrubber liquor will have a high and varying chloride content derived both from the coal and from the sometimes brackish estuarine Nanticoke River water which will be used as the primary source of scrubber make-up. The waste landfill, occupying 165 acres (67 hectares), is located as shown in Figure 2. The full disposal site will be large enough to provide a wooded buffer for the landfill and the necessary haul road.

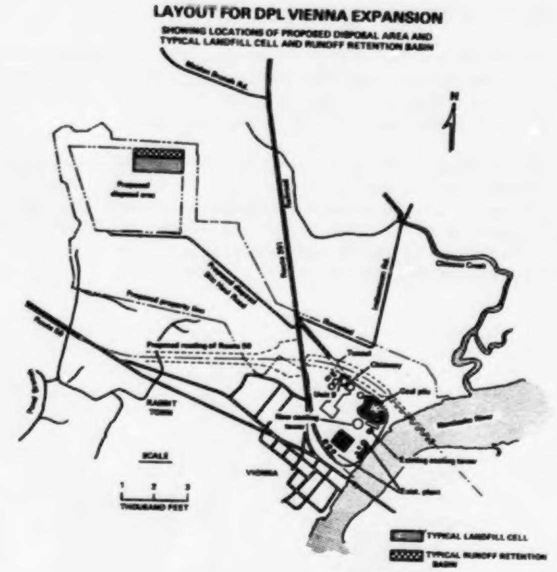

LAYOUT FOR DPL VIENNA EXPANSION
SHOWING LOCATIONS OF PROPOSED DISPOSAL AREA AND TYPICAL LANDFILL CELL AND RUNOFF RETENTION BASIN
N
Proposed disposal area
Proposed property line
Proposed routing of Route 50
Tunnel
Chimney
Coal pile
RABBIT TOWN
VIENNA
Existing cooling tower
Exist. plant
SCALE
1
2
3
THOUSAND FEET
TYPICAL LANDFILL CELL
TYPICAL RUNOFF RETENTION BASIN

Figure 2

Figure 3 depicts an artists concept of the appearance of the completed landfill at the disposal site.

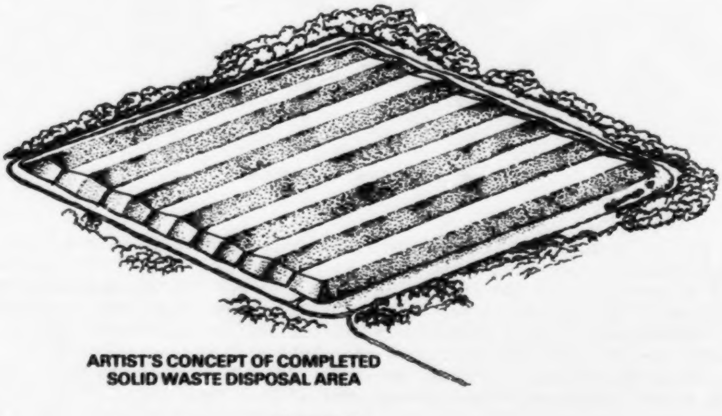

ARTIST'S CONCEPT OF COMPLETED
SOLID WASTE DISPOSAL AREA

Figure 3

Resources at Risk

Escape of contaminated leachate or surface runoff from the landfilled utility wastes could potentially affect a drinking water aquifer, the local terrestrial ecology, and a spawning area for commercially and recreationally significant striped bass (rockfish) that range the Chesapeake Bay and the offshore Atlantic Ocean.

Of the eight aquifers at Vienna, only two, the water table aquifer and a confined aquifer 300 feet (91 m) below land surface, are suitable for domestic use. The water table aquifer is 100 feet (30.5 m) thick, is low in dissolved solids, and is relatively free of man-made pollution. Elevated iron concentrations and the sporadic presence of heavy metals have been noted, however. The Nanticoke aquifer, 300 feet (91 m) below land surface, is relatively high in pH, dissolved solids, and hardness, and although used for individual domestic supplies may be abandoned in the near future in favor of the water table aquifer as a municipal water source for the town of Vienna.

At Vienna, terrestrial and aquatic ecology are closely related because of their mutual dependance on the surface streams which reticulate the area. Feeder streams of Chicone Creek and Otter Pond Branch arise in the vicinity of the proposed disposal area. Chicone Creek flows eastward to the Nanticoke River and Otter Pond Branch flows south to the Chicamacomico River which drains into Fishing Bay and thence to the Chesapeake Bay. There is concern that contaminated runoff in sufficient concentration could affect the life cycles of the bald eagle and the Delmarva fox squirrel, both of which are protected and known to be in the vicinity, or to the eastern tiger salamander and eastern narrow mouthed toad, which favor similar environments but which have not been found in the vicinity. Major public interest, however, centers on the protection of striped bass in the adjacent Nanticoke River during the critical spring spawning season.

Expected Quality of Leachate and Runoff

Review of the literature concerning leachate from fixed wastes suggested that solids concentrations, mostly calcium and sulfate ions, would be high, approaching the limits of solubility, and that the coal ash would contribute an abundant supply of heavy metals (8). Leachate studies carried out by the utility on six different synthetic waste mixtures (scrubber sludge from an existing station was mixed with fly ash, lime, and sodium chloride in varying proportions) yielded samples that produced leachates high in dissolved solids and heavy metals and which showed variability both between mixes and within separate cores of the same mix. For example, total dissolved solids varied between 500 to 13,000 mg/l. For the purposes of the evaluation process, a set of estimated leachate concentrations was developed by JHU/APL (6), and is shown with other related information in Table 1 below.

No direct data were available to assess the probable quality of the runoff from blended but unfixed flyash and lime. The predicted leachate concentration shown in Table 1 may be considered an upper bound. Another estimate was made from data for runoff from fixed wastes at the Elrama plant of Duquesne Lighting Company (9) and which are similar to those from runoff from a test pad of like material placed at Vienna by DPL (1). These concentrations are also shown in Table 1. Runoff quality at Vienna has been predicted to lie between the predicted and observed values shown in Table 1 (6). For comparison, National Interim Primary and Secondary Drinking Water Standards are also shown in Table 1.

TABLE 1

Comparison of Estimated Leachate Concentrations with EPA Primary and Secondary Drinking Water Standards
(all concentrations mg/l except pH)

	Concentration		
Contaminant	Predicted for Leachate	Observed in Runoff from Fixed Wastes	Permitted Maximum
			Primary Standards
Arsenic	0.094	0.017	0.05
Barium	1.0	0.0075	1.0
Cadmium	0.21	0.01	0.01
Chromium	0.001	0.05	0.05
Lead	0.005	0.05	0.05
Mercury	0.005	0.001	0.002
Selenium	0.12	0.009	0.01
Silver	<0.001	0.05	0.05
			Secondary Standards
Chloride	2970	71.3	250
Iron	0.86	0.20	0.3
Manganese	2.39	0.42	0.50
Sulfate	1350	1336	250
Zinc	5.4	0.25	5.
Total Dissolved Solids	8800		500
pH	7.5	7.95	6.5 - 8.5

STUDY OF BASIN OPERATION

For the analysis of the ability of the runoff retention basin to protect the local ecology from the effects of pond overflow, interest centered on three factors: the frequency of basin overflows, their magnitude, and the threshold level of their significance. Uncertainty over the sensitivity of the species at risk as well as over the probable concentration of overflowing contaminants in ambient waters made impossible the designation of specific levels of hazard to be associated with specific measures of overflow (10). This inability to identify specific levels of hazard focused attention on the retentive ability of the basin. For only a few spills, putatively occurring during periods of generally high runoff and adequate dilution, a low level of hazard could be assumed. Conversely, high levels of spill frequency or magnitude might or might not suggest hazard, but could certainly be interpreted as an indicator of unmanageability, suggesting that other means for controlling contamination be employed. As a practical matter, DPL has agreed to maintain capacity in the basin for the 10-year, 24-hour storm which thereby provides an objective working criterion to which the results of simulated operation of the basin can be compared.

Proposed Design and Operation of Basin

The collection basin, as described by DPL, will be rectangular and will have a bottom area of 91,254 square feet (0.85 hectares), be six feet (1.8 m) deep with the weir elevation set at five feet (1.5 m), and have surface dimensions of 225 feet (69 m) by 490 feet (140 m) for a surface area of 2.53 acres (1.0 hectares). The basin will be contained on three sides by an earthen dike with interior slopes of 2 (horizontal) to 1 (vertical) and on the fourth by the working face of the landfill where the interior slope, controlled by the side slopes of the landfill itself, will be 4:1 (horizontal to vertical). DPL initially proposed that make-up water be pumped from the basin at an average rate of 40 gallons (0.15 m^3) per minute. For the simulation, this rate was assumed to be the equivalent of a capacity factor of 100%. For other assumed capacity factors of 82% and 67% respectively, the pumping rate was reduced to 33 (0.13 m^3/min) gpm and to 27 gpm (0.10 m^3/min). To test the potential application of alternate operating rules, pumping rates of 50-, 60-, and 70- gpm (0.19-, 0.23-, and 0.26 m^3/min) were also examined. For simulations examining the effects of scheduled annual shutdowns, slight upward adjustments were made to pumping rates to assure that the same total annual volumes of water were being pumped over a pumping year reduced by a shutdown as during a year with no shutdown. No allowance was made for reduction of basin volume due to sediment or for channel storage in the collection system. Throughout the study, the full cell surface area of 16.5 acres (6.7 hectares) was employed on the assumption that the full area would always drain to the pond. In practice, when less than the whole cell area is covered by blended wastes prior to completion of the first full lift, contaminant concentrations in the runoff will be proportionally less than the potential maximum. However, if the wastes are placed in 4-foot lifts, this condition will prevail less than 10% of the time, and the analysis should therefore not be considered unduly conservative.

For their own analyses, the utility and its consultants employed a runoff coefficient of 0.5. This was felt by the PPSP to represent a reasonable long-term value for estimating total long-term infiltration into the pile, but to be possibly inappropriate for individual, high magnitude, low frequency storm events where surface saturation soon converts all incident precipitation into runoff. In practice, the surface runoff coefficient will vary as a function of antecedent precipitation, which can be accounted for by any of several antecedent precipitation indices; the choice and application of such indices can be quite subjective. To provide general insight into the possible effects of variable surface saturation without becoming involved in the selection and use of an antecedent precipitation index, the APL analysis employed an average runoff coefficient of 0.8 in addition to the coefficient value of 0.5 used by DPL.

For a runoff coefficient of 0.5, one inch (2.54 cm) of rain represents a capacity requirement of 39,023 cubic feet (1105 m^3); for a runoff coefficient of 0.8 this requirement increases to 57,104 cubic feet (1617 m^3). For the 10-year, 24-hour storm, before allowance is made for pumping or evaporation, 4.3 acre-feet (5305 m^3) of storage are required for a runoff coefficient of 0.5, and 6.9 acre-feet (8510 m^3) of storage are required for a runoff coefficient of 0.8. Each of these demands includes an allowance for precipitation directly onto the basin surface as well as onto the landfill surface area.

Analysis of Continuous Operation Using Daily Data

A computer tape of total daily precipitation and average daily temperature for nearby Salisbury, Maryland for the period July 20, 1948 to December 31, 1978 was obtained from the National Weather Service, and these data in their entirety were used to simulate the performance of the proposed basin. Results reported in this paper cover the thirty-year period August 1, 1948 to July 31, 1978; this period was chosen *a posteriori* over the more conventional calendar year in order to include the effects of relatively heavy precipitation in early August 1948. Some initial processing of the daily meterological data was required. Trace amounts of rainfall were changed to zero and missing temperature records for five discrete days were estimated as arithmetic averages of the days immediately preceding and following. See Appendix A. Adjusted precipitation and temperature data were taken from the data tape; daily potential evapotranspiration was computed by the method of Yoshioka (11) and applied over the basin surface area at the beginning of each day. When temperature was 32°F (0°C) or below, runoff was held in frozen storage until released by warming temperatures. None of the required temperature adjustments occurred at a time when freezing conditions might have retarded runoff, but some negligible effect on the estimated quantity of evaporation is likely.

For the 30 year period August 1, 1948 to July 31, 1978, the average annual precipitation was 44.83 inches (113.9 cm). Annual maximum daily precipitation ranged from 1.60 inches (4.1 cm) on June 10, 1966 to 5.44 inches (13.8 cm) on September 12, 1960. The highest average monthly precipitation occurred in August, with 5.88 inches (14.9 cm), and the lowest average monthly precipitation occurred in April, with 2.99 inches (7.6 cm). Average daily temperature ranged from 6°F (-14.4°C) on January 17, 1965 to 89°F (31.7°C) on July 23, 1978. Overall average daily temperature was 56°F (13.3°C); minimum average monthly temperature was 36°F (0.6°C), for January, and the maximum average monthly temperature was 76.7°F (24.8°C) for July.

As discussed above, runoff coefficients of 0.5 and 0.8 were assumed, along with withdrawal rates of 27-, 33-, 40-, 50-, 60-, and 70 gpm (0.10-, 0.13-, 0.15-, 0.19-, 0.23- and 0.26 m^3/min). The basin was assumed empty at the beginning of the operation.

Results for Continuous Basin Operation

For a runoff coefficient of 0.5, no spills occurred during the entire period of study regardless of the withdrawal rate.

For a runoff coefficient of 0.8, the frequency and total magnitude of spills (in millions of cubic feet and thousands of cubic meters) are shown in Table 2 below. Table 2 also notes the effect of a few large rainfall events, including those of early August, 1948.

These studies yielded four principal results:

a. For a runoff coefficient of 0.5, there were no computed spills (overflow events) for water withdrawal rates ranging from 27 gpm to 70 gpm (0.10 to 0.26 m^3/min).

b. For a runoff coefficient of 0.8 and a pumping rate of 27 gpm, there were 369 computed spills, overflowing 11.93 million cubic feet (mcf) (337.8 thousand cubic meters (tcm)) of water. This is equivalent to an average spill rate of 0.37

TABLE 2
Estimated Number of Spills and Spill Magnitude for Proposed Runoff Collection and Recycling Basin at Vienna, Maryland for a Runoff Coefficient of 0.8
(Using Salisbury Meteorological Data, August 1, 1948 - July 31, 1978)*

Make-Up Withdrawal Rate		Number of Days Having Spills	Total Magnitude of Water Spills	
(Gallons per Minute)	(Cubic Meters per Minute)		(Million Cubic Feet)	(Thousand Cubic Meters)
70	(0.26)	1[1]	0.01	(0.4)
60	(0.23)	2[2]	0.02	(0.6)
50	(0.19)	4[3]	0.09	(2.6)
40	(0.15)	30[4]	0.76	(21.6)
33	(0.12)	135[5]	4.34	(122.9)
27	(0.10)	369	11.93	(337.8)

---

1. August 4, 1948; rainfall 4.18 in. (10.6 cm) on August 3, 3.49 in. (8.9 cm) on August 4.
2. August 4-5, 1948.
3. August 4-5, 1948 plus two other independent occurrences.
4. Includes eight instances (16 days total) of continuous spill on two successive days; of these 5 occurred between August 1948 and April 1949.
5. Twenty-seven instances of occurrences on successive days (longest single occurrences: May 4-6, 8-9, 1978).

*No spills estimated for runoff coefficient of 0.5.

cubic feet per second (cfs) (0.64 m3/min) persisting throughout each day of spillage. The peak estimated spillage rate was 2.6 cfs (4.4 m^3/min) persisting through the day of the spill.

c. For a runoff coefficient of 0.8 and a pumping rate of 40 gpm (0.15 m^3/min), there were 30 computed spills, overflowing 0.76 mcf (21.6 tcm) of water for an average spillage rate of 0.29 cfs (0.50 m^3/min) throughout each day of spillage. The peak estimated spillage rate was 1.3 cfs (2.2 m^3/min) throughout the day of spillage.

d. Although withdrawal rates in excess of 40 gpm (0.15 m^3/min) sharply reduced the number of overflows, complete elimination of overflows did not occur at a runoff coefficient of 0.8 for the withdrawal rates studied.

These analyses thus showed sensitivity to runoff coefficient and to make-up withdrawal rate, but monthly or seasonal distributions of overflow events were not determined in this portion of the analysis.

Estimating Effects of Shutting Down Plant During Spawning Season

Under some circumstances, the plant could be shut down for a protracted period. There was concern that consequent cessation of the withdrawal of runoff for scrubber make-up would increase the frequency and quantity of overflows, which could pose environmental problems, especially during the spring spawning period. To resolve this concern it became necessary to examine how the spillage frequency and magnitude during the spring would be affected if the plant were to be shut down.

This shutdown study was done in two phases: first, the simulation was run for a spectrum of annual 3- and 6-week shutdown periods from March 24 to June 26 and the total number and quantity of spillages for the 30-year period were compared under both shutdown and non-shutdown conditions. Following this, for one selected annual three-week shutdown period and an overlapping six-week annual shutdown period, the increase in number and quantity of spillages was determined.

Nominal pumping rates of 27 gpm (0.10 m^3/min) and 40 gpm (0.15 m^3/min) were used for base case, non-shutdown conditions in order to estimate the quantities of water that would be recycled at capacity factors of 68% and 100%, respectively. For the shutdown cases, these nominal rates were then adjusted upward so that the total volume of water recycled in the remaining 49 or 46 weeks of each year would be equal to the volume otherwise recycled at the nominal rates during a full 52 weeks. Thus, the 27 gpm (0.10 m^3/min) nominal recycling rate was increased to 28.7 gpm (0.11 m^3/min) for the three-week shutdown study, and to 30.5 gpm (0.116 m^3/min) for the six-week shutdown study. Similarly, the 40 gpm (0.15 m^3/min) nominal rate was adjusted to 42.4 gpm (0.16 m^3/min) and 45.3 gpm (0.17 m^3/min) for the three-week and six-week shutdown studies, respectively.

Table 3 shows the results of the eight three-week studies and the six six-week studies for the thirty full years of data which were used, for runoff coefficients of both 0.5 and 0.8. Table 4 compares overflow frequency and quantity under shutdown and non-shutdown conditions for annual shutdowns scheduled for each three-week period April 25 -May 15 and for each six-week period April 14 - May 25.

TABLE 3

30-Year Comparison of Total Number of Spillages and Quantity Spilled For No Shutdown Base Case and For Annual Shutdowns Scheduled For Specific Periods

TIME OF SCHEDULED SHUTDOWN - 3 WEEK DURATION

Make-Up Withdrawal Rate		Runoff Coefficient	No Shutdown		March 24 to April 13		April 4 to April 24		April 14 to May 4		April 25 to May 15		May 5 to May 25		May 16 to June 5		May 26 to June 15		June 6 to June 26	
Nominal	Adjusted*		No.	Qty.	No.	Qty.	No.	Qty.	No.	Qty.	No.	Qty.	No.	Qty.	No.	Qty.	No.	Qty.	No.	Qty.
gpm mcm	gpm mcm																			
27 (0.10)	28.7(0.11)	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		0.8	369	11.93 (337.8)	369	11.95 (338.6)	370	11.85 (335.7)	381	11.81 (334.6)	374	11.87 (336.0)	359	11.89 (336.7)	359	11.95 (338.5)	364	12.01 (340.1)	363	12.03 (340.8)
40 (0.15)	42.4(0.16)	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		0.8	30	0.76 (21.6)	35	0.88 (25.0)	27	0.75 (21.2)	23	0.70 (19.9)	21	0.69 (19.6)	23	0.70 (19.9)	22	0.70 (19.9)	25	0.78 (22.2)	22	0.80 (22.8)

TIME OF SCHEDULED SHUTDOWN - 6 WEEK DURATION

Make-Up Withdrawal Rate		Runoff Coefficient	No Shutdown		March 24 to May 4		April 4 to May 15		April 14 to May 25		April 25 to June 5		May 5 to June 16		May 16 to June 26	
Nominal	Adjusted*		No.	Qty.	No.	Qty.	No.	Qty.	No.	Qty.	No.	Qty.	No.	Qty.	No.	Qty.
gpm mcm	gpm mcm															
27 (0.10)	30.5(0.12)	0.5	-	-	1	0.04 (1.2)	2	0.04 (1.0)	1	0.02 (0.6)	-	-	-	-	-	-
		0.8	369	11.93 (337.8)	404	12.06 (341.6)	394	12.00 (339.7)	396	12.02 (340.6)	367	12.07 (341.9)	358	12.09 (342.3)	360	12.12 (343.3)
40 (0.15)	45.3(0.17)	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		0.8	30	0.76 (21.6)	43	0.97 (27.6)	31	0.90 (25.6)	35	0.97 (27.6)	31	1.01 (28.5)	32	1.06 (29.9)	35	1.16 (32.9)

*Adjusted make-up withdrawal rate is pumping rate required to equate total annual volume pumped during non-shutdown periods to total volume pumped under conditions of "No Shutdown".

Quantity of spills in millions of cubic feet (thousands of cubic meters in parentheses).

gpm - gallons per minute
mcm - cubic meters per minute

TABLE 4

Effects of Plant Shutdowns on Hypothetical Overflows From Runoff Collection and Recycling Basin
August 1, 1948 - July 31, 1978

THREE-WEEK SHUTDOWN APRIL 25 - MAY 15

Make-Up Withdrawal Rate	Runoff Coefficient	WITHOUT SHUTDOWN			WITH SHUTDOWN			INCREASE		
Nominal Actual* gpm mcm gpm mcm		No. of Years Having Overflow	No. of Overflows	Total Spillages**	No. of Years Having Overflows	No. of Overflows	Total Spillage**	No. of Years Having Overflows	No. of Overflows	Total Spillage
27 (0.10) 28.7 (0.11)	0.5	-	-	-	-	-	-	-	-	-
	0.8	6	23	0.74 (21.0)	11	58	1.47 (41.6)	5	35	0.73 (20.6)
40 (0.15) 42.7 (0.16)	0.5	-	-	-	-	-	-	-	-	-
	0.8	1	1	0.06 (1.8)	1	3	0.16 (4.6)	0	2	0.10 (2.8)
SIX-WEEK SHUTDOWN APRIL 14 - MAY 25										
27 (0.10) 30.5 (0.12)	0.5	-	-	-	1	1	0.02 (0.6)	1	1	0.02 (0.6)
	0.8	9	33	0.97 (27.4)	17	140	2.96 (83.8)	8	107	1.99 (56.4)
40 (0.15) 45.3 (0.17)	0.5	-	-	-	-	-	-	-	-	-
	0.8	1	1	0.06 (1.8)	3	13	0.40 (11.4)	2	12	0.34 (9.6)

* Adjusted make-up withdrawal rate is pumping rate required to equate total annual volume pumped during non-shutdown periods to total volume pumped under conditions of "No Shutdown".

** Quantity of spills in millions of cubic feet (thousands of cubic meters in parentheses).

gpm - gallons per minute
mcm - cubic meters per minute

It is seen from Table 3 that little change is noted in either the total number of spillages or total quantity of water spilled regardless of the period of shutdown. It an be observed that in some cases that there are fewer total spillages with shutdowns than without. It is believed that the increased pumping rate is sufficient to explain this difference; it should be noted that the total quantity spilled varies little whether there are increases or decreases in the number of spillages.

From Table 4, it is seen that marked increases in the number of spills occurred during the test periods, but that the actual increases in the quantity of water spilled amount to very little.

Both Table 3 and Table 4 show relatively infrequent occurrences of spills associated with six-week shutdowns when the runoff coefficient takes on the lower value of 0.5.

Satisfaction of Overflow Criterion

Examination of Tables 2, 3 and 4 show that for long pumping rates and a high runoff coefficient, meeting the criterion that there be no overflow except under conditions more extreme than the 10-year, 24-hour rainfall event might prove quite difficult. For a runoff coefficient of 0.5, no overflows were induced by the historical weather pattern used; for a runoff coefficient of 0.8, the same weather pattern led to a range of overflows from 1 to 369, depending on pumping rate. Clearly, for a sufficiently low runoff coefficient, no problem should be anticipated. But as runoff coefficient increases, so too will the number of overflows, modulated principally by pumping rate and to a very much lesser degree of evaporation.

For storms less than the design criterion, overflow could certainly be prevented by following an operating rule requiring that capacity for the full 10-year, 24-hour runoff be maintained at all times, once a design runoff coefficient has been agreed upon. Table 5 shows the capacity reservation requirement and the corresponding water surface elevation to be maintained for various pumping rates for a runoff coefficient of 0.8 if full contaminant of the 10-year, 24-hour event is to be achieved.

An alternative approach to the establishment of an operating rule is to rephrase the criterion such that no more than three overflows should occur within a thirty-year span. Table 5 also shows the mangitude of the third highest spill for each of the pumping rates studied (second highest for 60 gpm (0.23 m^3/min) and highest for 70 gpm (0.26 m^3/min)) for a runoff coefficient of 0.8. Ignoring, for the sake of discussion, statistical variation around that value, Table 5 then shows the necessary pond elevation to be maintained to contain the three largest spillages -based on recorded data - observed in 30 years.

SUMMARY AND CONCLUSIONS

1. The number of potential overflows which might be calculated is most highly sensitive to the assumed runoff coefficient. In reality, the runoff coefficient, now unknown, will not be a constant, but will vary directly with the degree to which the surface become saturated during an precipitation event. This is sometimes estimated indirectly by use of an antecedent precipitation index. No attempt was made to account for this variation in the computa-

TABLE 5

Storage Capacity to be Reserved and Basin Water Level Elevation to be Maintained to Hold Runoff from 10-Year, 24-Hour Storm and to Prevent Overflow More Than Three Times in Thirty Years (Based on Weather Data August 1, 1948 to July 31, 1978 - Runoff Coefficient (0.8)

Average Annual Make-Up Withdrawal Rate		Assuming Containment of Runoff from 10-Year, 24-Hour Storm (Runoff Coefficient 0.8)				Assuming Prevention of More Than Three Overflows in 30 Years			
		Storage Capacity to be Reserved to Contain 10-Year, 24-Hour Rainfall Concurrent with Pumping Rate		Maximum Water Elevation to be Maintained to Reserved Needed Storage Capacity		Storage Capacity Needed to Contain 3d Highest Overflow Rate* in 30-Years of Simulated Basin Operation		Maximum Water Level Elevation to be Maintained to Reserve Needed Storage Capacity	
(gpm)	(m^3/min)	(ft^3)	(m^3)	(ft^3)	(m)	(ft^3)	(m^3)	(ft)	(m)
70	(0.26)	289465	8070	2.2	0.67	14489	410	4.8	1.46
60	(0.23)	286890	8125	2.1	0.64	22185	630	4.7	1.43
50	(0.19)	288815	8180	2.1	0.64	52970	1500	4.5	1.37
40	(0.15)	290740	8235	2.1	0.64	66345	1880	4.3	1.31
33	(0.12)	292090	8270	2.1	0.64	98431	2790	3.5	1.07
27	(0.10)	293240	8305	2.1	0.64	107683	3050	3.3	1.00

was made to account for this variation in the computation; it is expected that the runoff coefficient values of 0.5 and 0.8 used in the analysis constitute a sufficiently broad range to encompass the true values that may be encountered. It is worth noting, in passing, that a runoff coefficient of 0.5 implies that without evaporation, half of the total precipitation will enter the waste. Had not analysis of waste behavior shown that saturation would not be completed in the three years of active placement of waste in the cell, the potential emergence of this fraction of precipitation as leachate or seepage would have been a matter of some concern.

2. In association with any assumed runoff coefficient, the system is also sensitive to the rate at which make-up is withdrawn. For a runoff coefficient of 0.5, a withdrawal rate of 27 gpm (0.10 m^3/min) was sufficient to prevent any spillage. For a runoff coefficient of 0.8, any pumping rate for withdrawal of make-up in excess of approximately 40 gallons per minute (0.15 m^3/min) effectively eliminated overflows for all except the most extreme conditions. As noted in Table 2, not all of the individual days having spills were isolated instances; on several occasions, water spilled continuously over periods of several days. For a runoff coefficient that varies with the state of surface saturation, a correspondingly varying make-up withdrawal rate might be feasible. Whether this is desirable or practicable is an engineering detail left to the applicant.

3. Although the number of overflows during 3- or 6-week shutdown periods showed increases, the quantities of runoff spilled remain small.

4. Although the number of spills varied greatly as a function of both runoff coefficient and withdrawal rate, it is seen that with careful matching of facilities design and operation to expected demand, a basin designed to hold contaminated runoff for recycling represents a workable approach to the management of an otherwise serious waste disposal problem.

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APPENDIX A

Adjustments to Salisbury Meteorological Data for Missing Values of Average Daily Temperature July 20, 1958 to December 31, 1978

Date for Which Temperature Data Missing	Latest Preceeding Data Date	Temperature °F	°C	Earliest Following Data Date	Temperature °F	°C	Estimated Temperature °F	°C
March 16, 1949	March 15, 1949	41	(5)	March 17, 1949	40	(4)	41	(5)
March 30, 1951	March 29, 1951	62	(17)	March 31, 1951	49	(9)	55	(13)
April 18, 1953	April 17, 1953	53	(12)	April 20, 1953	42	(6)	50	(10)
April 19, 1953	April 17, 1953	53	(12)	April 20, 1953	42	(6)	46	(8)
December 7, 1953	December 6, 1953	50	(10)	December 8, 1953	44	(7)	47	(8)

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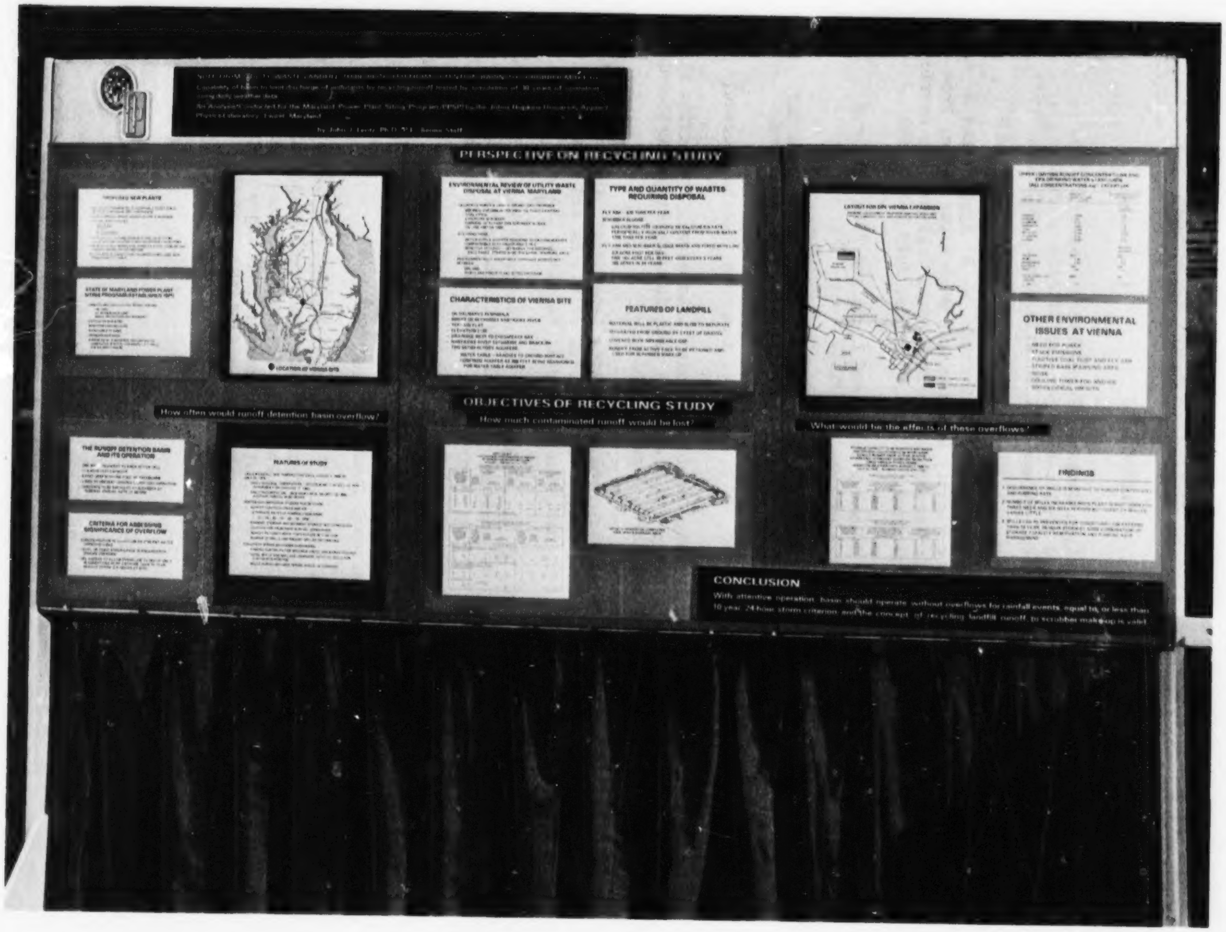

[illegible]

Capability of basin to limit discharge of pollutants by recycling runoff tested by simulation of 30 years of [illegible] using daily weather data

An Analysis conducted for the Maryland Power Plant Siting Program (PPSP) by the Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland

by John J. [illegible] Ph.D. P.E. Senior Staff

PERSPECTIVE ON RECYCLING STUDY

PROPOSED NEW PLANTS

STATE OF MARYLAND POWER PLANT SITING PROGRAM ESTABLISHED 1971

LOCATION OF VIENNA SITE

ENVIRONMENTAL REVIEW OF UTILITY WASTE DISPOSAL AT VIENNA, MARYLAND

TYPE AND QUANTITY OF WASTES REQUIRING DISPOSAL

CHARACTERISTICS OF VIENNA SITE

FEATURES OF LANDFILL

LAYOUT FOR DPL VIENNA EXPANSION

OTHER ENVIRONMENTAL ISSUES AT VIENNA

- NEED FOR POWER
- STACK EMISSIONS
- FUGITIVE COAL DUST AND FLY ASH
- STRIPED BASS SPAWNING AREA
- NOISE
- COOLING TOWER FOG AND ICE
- SOCIOLOGICAL IMPACTS

OBJECTIVES OF RECYCLING STUDY

How often would runoff detention basin overflow?

THE RUNOFF DETENTION BASIN AND ITS OPERATION

CRITERIA FOR ASSESSING SIGNIFICANCE OF OVERFLOW

FEATURES OF STUDY

How much contaminated runoff would be lost?

What would be the effects of these overflows?

FINDINGS

CONCLUSION

With attentive operation, basin should operate without overflows for rainfall events equal to, or less than 10 year, 24 hour storm criterion and the concept of recycling landfill runoff to scrubber makeup is valid.

PB82-223611

ZERO DISCHARGE VIA WATER REUSE IN COOLING TOWERS

WATER REUSE SYMPOSIUM II
WASHINGTON D.C.
AUGUST 23-28, 1981

PUCKORIUS & DANNENBAUM

Paul R. Puckorius
30440 Stagecoach Blvd.
Evergreen, Colorado 80439

Teague G. Harris
4543 Post Oak Place Dr.
Houston, Texas 77027

INTRODUCTION

Concept

The sidestream softening process allows the reuse of cooling tower blowdown. These wastewaters, together with once-through cooling water discharges, comprise the greatest volume by type of all industrial wastewater discharges. Other plant waste streams may be recycled as makeup to the recirculating water to further reduce discharges. Zero discharge operation is possible in certain situations.

Although the concept of sidestream softening is simple, cost effective process design and the proper cooling water treatment program require experienced selection. The high levels of total dissolved solids (TDS) resulting from increased cycles of concentration significantly impact the chemistry of the softener and the cooling water. Further, interactions between the softener and the water treatment chemicals can be detrimental to the desired function of both.

Incentives

The major incentives to industry for the construction and operation of a zero blowdown or zero discharge sidestream softening system are(1,2):

1. Regulatory. EPA's effluent limitations for chromium and zinc require blowdown treatment or a switch to alternate corrosion inhibitors. While the national goal of zero discharge may seem a distant reality, there are a number of sensitive watersheds where zero discharge or reduced salinity discharges by industries are presently required.

2. Economic. Depending on an individual industry's costs for water, pretreatment, and wastewater treatment, sidestream softening can provide operating cost savings to yield a capital cost payback period of three years or less.
3. Water Availability. In some arid regions of the country, the availability of water has or may soon become limited to such an extent that reuse will be the only alternative.
4. High Chromate Corrosion Protection. Widely recognized for years as the best corrosion inhibitor for cooling water systems, zero blowdown sidestream softening offers the continued use of high chromate treatments.

Advantages and Disadvantages

The advantages of zero blowdown sidestream softening are:

1. Reduction of raw water makeup to cooling towers.
2. Elimination of cooling tower blowdown and its treatment.
3. Removal of the major scale forming species in cooling water systems: Ca^{++}, Mg^{++}, $PO_4^{=}$, and SiO_2.
4. Since hexavalent chromate is not removed in the softener but recycled back to the cooling system, high chromate levels can be maintained at low cost.
5. Suspended solids, such as dust, corrosion products, and biological slime masses, are removed in the sidestream softening system by clarification and filtration.
6. Uses relatively low cost chemicals: lime, caustic, soda ash, carbon dioxide, and/or acid.
7. Produces a sludge which is readily dewatered and, in Texas, does not require hazardous waste class landfilling.
8. The high pH in the softener is toxic to most microbiological organisms.

The disadvantages of zero blowdown sidestream softening are:

1. The system is almost a closed aqueous system: all constituents added will cycle up in concentration unless removed by the sidestream softener and filter, including waste stream organics and process leaks.
2. Recirculating waters will be high in total dissolved solids, including chlorides and sulfates, which will increase the potential for corrosion.
3. Successful operation of the sidestream softener requires increased levels of operator attention. In addition, if other plant waste streams are to be reused, then communication between different operators concerning spills, unscheduled blowdowns, etc., is necessary to prevent cooling system upset.
4. Cooling tower drift will contain higher TDS concentrations of dissolved solids which will result in a salt buildup on surrounding plant equipment. This can accelerate corrosion of external metal surfaces and cause arcing of transformers.

5. A sludge is produced which must be dewatered and disposed of.

Present and Proposed Installations

1. Union Carbide Gaseous Diffusion Plant, Oak Ridge, Tennessee.
2. Georgia-Pacific petrochemical plant, Plaquemine, Louisiana.
3. Southern California Edison Coolwater Electric Generation Plant, Daggett, California.
4. USS Chemicals Petrochemical Plant, Houston, Texas.
5. Tosco Corporation Oil Refinery, Bakersfield, California.
6. W.R. Grace Petrochemical Plant, Memphis, Tennessee.
7. Bison Nitrogen, Oklahoma
8. Martin Drake Municipal Power Plant, Colorado Springs, Colorado.
9. Sierra Pacific Power Plant, Reno, Nevada.

SELECTION OF REUSE WATERS

Evaluation for Reuse in Cooling Water System

Cooling tower blowdown is the immediate candidate from a plant's various waste streams for reuse as makeup to the recirculating cooling water. The suitability for reuse of any waste stream is based on an evaluation of the interactions between the reuse stream, the sidestream softening system, the cooling water system. The primary objective is the continuous protection of the heat exchange equipment from heat transfer loss (due to scaling and fouling) and from metal loss and failure (due to corrosion).

The flow rate, temperature, and chemical composition of the waste stream must be examined. The variation in the flow rate and composition are very important. Cyclic or intermittant flows may require equilization. The softener design should be based on a "worst case" influent composition. In addition, the chemical composition of the waste stream should be evaluated as follows:

1. Deposition Potential. The softener will remove calcium, magnesium, alkalinity, silica, phosphates, and suspended solids. Other potential foulants and scale forming species must be controlled by inhibitors or removed by an additional process in the sidestream treatment. Waste streams with scaling potential before softening include ammonia condensates, phosphate treated boiler blowdown, cation regenerant waters, and calcium brines. Wastes streams with fouling potential include API effluent, oil condensate, and iron waters.
2. Corrosion Potential. The metallurgy of heat exchange equipment and the selected operating pH of the recirculating water must be considered when evaluating a waste stream's corrosion potential. Certain species can cause severe problems with

certain metals, such as ammonia on copper alloys. Waste streams which are high in TDS, particularly chlorides and sulfates, are more corrosive. Waste streams which are corrosive include ion exchange rinse waters and desalter wash waters.

3. Biofouling Potential. Waste streams which contain biodegradable organics, nutrients (phosphates, ammonia, nitrites, nitrates), and microorganisms increase the potential for biofouling of heat exchanges. Waste streams with biological growth potential include sewage effluent, biological pond effluent, storm water, and high organic process streams.
4. Interference with Softener Operation. Treatment chemicals already contained in a waste stream, such as scale inhibitors, dispersants, and surfactants, may interfere with the precipitation reactions and the stability of the sludge bed in the clarifier.
5. Interference with Cooling Water Treatment Program. Treatment chemicals already contained in a waste stream and other contaminants may be incompatible with the treatment program currently used in the cooling tower recirculating water.

SIDESTREAM SOFTENING DESIGN ANALYSIS

Estimate Water Quality

The quality of the makeup water and the recirculating cooling water must be defined or estimated to begin the sidestream softener design. The input location of a reuse stream will vary depending on its water quality. Relatively clean water may be added directly to the cooling tower basin (see Figure 1). Reuse streams containing high suspended solids but of otherwise acceptable quality may be input just before the filters in the sidestream treatment train. The remaining reuse streams can then be routed through the softener.

Thus, the makeup waste may be a blend of plant water and a reuse stream. Quality variations in both should be considered in defining a design makeup water composition which will reflect the worst reasonable operating conditions. Recirculating water quality must be estimated and then checked after sizing the softener flowrate.

Cooling Water Scale Control Limits

Calcium Carbonate ($CaCO_3$). Calcium carbonate scale is usually prevented by controlling the pH of the cooling water in the range of 6.0 to 7.0. Carbonate concentrations are so low in this range that the calcium carbonate solubility product will not be exceeded if the free calcium ion limit based on calcium sulfate scale is not exceeded. Some cooling waters are being operated in the higher pH ranges of 7.0 to 8.5. There are advantages for the sidestream softening process in this practice: (1) less alkali is required in the softener, (2) less acid is required to adjust pH, and (3) total dissolved solids, and thus corrosion potential, will be reduced due to reduced acid usage. However, calcium carbonate scale control is more critical. While most of the total carbonate species is still in the form of bicarbonate, carbonate levels could become significant if the alkalinity is not controlled.

In these high pH systems, the saturation pH (pHs) should be calculated and used to control both calcium ion and bicarbonate ion in the cooling water. The equation as first presented by W. F. Langelier used to estimate pHs does not account for ion pairing reactions which become significant in the higher levels of total dissolved solids found in zero blowdown cooling water systems. A corrected pHs equation has been developed by McGaughey and Matson (3) based on ion association theory.

Calcium Sulfate ($CaSO_4$). Calcium sulfate can be controlled by limiting the calcium ion concentration. Klen (4) found in extensive pilot test work that if the calcium concentration in the cooling water was maintained below 280 mg/l, or 700 mg/l as $CaCO_3$, then calcium sulfate scale did not form, even with sulfate concentrations as high as 50,000 mg/l.

Silica (SiO_2). Silica scale can be prevented by limiting the silica concentration. An empirical solubility relationship was developed by Matson and Harris (5) using data from the literature. Amorphous silica will slowly polymerize to form polymeric colloids which can then adhere to heat exchanger surfaces to form a hard scale. The relevant temperature to use in this empirical equation is that of the coldest heat exchanger.

Cost-Effective Process Selection

Sidestream softening design methodology has been discussed by Matson and Harris (7). The general treatment process (Figure 1) is here considered to be a softener (solids contact reactor clarifier), a pH adjustment tank, and gravity or sand filters. An optional unit process could be added after the filters for the removal of salinity, e.g., electrodialysis or reverse osmosis. Its purpose would be to reduce the total dissolved solids concentrations. In particular, it may be warranted to control chloride due to its corrosivity.

Lime (calcium hydroxide) or caustic (sodium hydroxide) is added to the softener reaction zone to raise the pH to between 10.5 and 11.0. The selection is based on a cost analysis. While lime is usually less expensive, it will produce more sludge than caustic. Soda ash addition will be required if insufficient carbonate alkalinity is available to precipitate all the calcium.

Dissolved silica is removed by an adsorption onto or ion exchange reaction with magnesium hydroxide floc. If silica scaling controls the design, then magnesium, either as magnesium oxide, magnesium sulphate, or magnesium chloride, addition will be required to remove silica during softening. Use of dolomitic lime may also satisfy the magnesium requirement for silica removal.

The lowering of pH may be adjusted by acid, most commonly sulfuric acid, or by carbon dioxide. Sulfuric acid use increases TDS by adding sulfates to the cooling water. Carbon dioxide can control pH, however, it is air stripped in the cooling tower so excess carbon dioxide must be used. Futhermore, carbon dioxide does not destroy alkalinity, and thus in certain situations acid addition is mandatory.

The essentials of design involve constucting mass balances for the cooling water sidestream softener system, setting maximum water quality limits for the recirculating water, determining softener efficiency, and calculating the sidestream flow rate. The sidestream flow rate is the most important design parameter as it predetermines the sizes of the equipment in the softening loop and the chemical feed rates. Thus, the primary objective is to calculate the minimum (most economic) flow rate possible to achieve a specified cooling water quality.

Ions such as sodium, potassium, sulfate, and chloride are not removed in the softening process. In zero blowdown operations (Figure 2), the concentrations of these ions are controlled by drift losses, thus:

$$\frac{C_w}{C_m} = \frac{Q_m}{Q_d}$$

where:

Q_m = makeup water flow rate
Q_d = drift rate
C_m = concentration of conservative material in the makeup water
C_w = concentration of conservative material in the cooling water

The concentration of any conservative substance in the makeup water not removed in the softening process is:

$$C_w = C_m \frac{(Q_m)}{(Q_d)}$$

The nonconservative dissolved solids that are removed in the softener are calcium, magnesium, carbonate, and silica. A mass balance over the cooling tower yields the steady state expression:

$$Q_m C_m + Q_s C_s = Q_d C_w + Q_s C_w$$

where:

Q_s = the flow rate through the softening loop
C_s = the softener effluent concentration of removable dissolved solids

To simplify this expression, it is assumed that the flow rate through the softening loop is much larger that the drift loss rate (Q_s<<Q_d), so that the drift term is dropped from the equation. Solving for the ration of flow rate through the softener to makeup flow rate:

$$\frac{Q_s}{Q_m} = \frac{C_m}{C_w-C_s} = \text{Design Ratio}$$

This equation defines the design ratio (Q_s/Q_m) which may be calculated for each scale forming dissolved specie that is removed in the softener. Makeup water concentration (C_m) for each specie is set at a level below which there is no tendency for it to form scale. The highest design ratio controls the design; estimates of cooling water quality, chemical dosage rates, and sludge production can then be made.

COOLING WATER TREATMENT PROGRAM

Nature of System

The zero blowdown sidestream softening system is practically a closed cooling system. Once materials enter the system, they will remain within the system unless they are removed in the softener, the filters, or by drift loss. The addition of lime, caustic, soda ash, and/or magnesium salts will precipitate calcium carbonate, magnesium hydroxide, and silica. The high pH and alkali in the softener will also remove iron, zinc, trivalent chromium, and phosphates.

Most suspended materials are removed, including turbidity, biological organisms, corrosion products, and some hydrocarbons. If any materials are precipitated, either due to the added chemicals or to reactions within the system, these are removed in the softener and filters.

Some materials entering this sytem are destroyed. An example is organics from either wastewater reuse or process contamination reacting with an oxidixing agent such as chlorine. Also, ammonia and some light hydrocarbons are air stripped from the recirculating water in the cooling tower.

However, materials that remain soluble in the presence of the various added chemicals and the high pH conditions will pass through the softener and filters to recycle within the system. This includes chlorides, sulfates, hexavalent chromates, molybdates, and others.

The treatment program must consider the uniqueness of this system. It requires specific chemicals to be utilized for deposit, corrosion and biological control which will protect heat exchange equipment from fouling and corrosion without adversely affecting the softener operation.

There are several treatment programs that can be used, depending upon the plant's requirements and preferences.

Deposition Control

Deposition control in cooling water systems generally refers to the control of scale and foulants. Scale control usually is accomplished by keeping the scaling minerals solubilized. Acid is frequently used, as are scale inhibitors such as phosphate esters, phosphonates, and polyacrylates. These inhibitors are very effective even at very low dosages of a few parts per million active. Their action is not fully understood, except that they keep the scaling minerals in solution even in severely scaling conditions.

Unfortunately, these inhibitors cannot tell the difference between scale formation on heat exchanger surfaces and precipitation in the softener They will cause the softener to operate very inefficiently. To offset the effect of these inhibitors, excess dosages of lime, caustic, and/or soda ash are necessary, and the effluent quality of the softener will be poor in terms of calcium hardness removal. At the same time, these scale inhibitors are removed in the softener and thus must be replenished. The other scale control agents that adversely affect the lime softener are lignins, tannins, alginates, and starches.

Some specific types of chemicals allow scale to form, but modify the crystals so that they do not adhere to the heat transfer surfaces. The action is referred to as "crystal modification." The scale becomes a sludge and is removed in the softener. There is usually no interference with softener operation. There are even indications of improved operation with efficient soda ash utilization and better effluent quality.

Another important part of deposition control in cooling water systems is the control of foulants. Foulants are usually suspended solids from a variety of sources - the air, the makeup water, and from the system itself. Organics from process leaks, storm water, and biological organisms can also contribute to fouling. Suspended solids often are controlled in cooling water systems by the use of dispersants or suspending agents. These are different types of chemicals; polyacrylates are the most commonly used. They act to break up and suspend deposits. Only a few parts per million are necessary, but they must be present at all times to hold the deposits in suspension.

Naturally, if these chemicals were used, the suspended solids from the softener would not settle well, resulting in overloading of the filters. There has not been an apparent need for these chemicals in other operating zero blowdown sidestream softening systems. However, there are some specific chemicals that can be utilized that would not affect the softener if this is necessary. The control of organic foulants, such as hydrocarbons and biological slime, is often accomplished with nonionic, low-foaming surfactants. These products, if added continuously at low dosages, may cause bed disruptions in the clarifier and carryover of sludge. If added on a slug basis, considerable bed disruption can occur. Certain surfactants can be recommended, however, which will cause minimum interference.

Corrosion Control

Corrosion control in cooling water systems refers primarly to protection of the heat exchanger tubing, but also should include all other metal components. The most sensitve is usually mild steel, although stainless steel and copper alloys often require special treatments or considerations.

In most plants, chromate-based inhibitors are being utilized to provide corrosion protection for the heat exchange equipment. Hexavalent chromate is not removed in the softener and thus is recycled to the cooling tower system. Sulfuric acid is generally used for pH control, resulting in a high sulfate level. Higher concentrations of chloride and sulfate require higher levels of corrosion inhibitor. This has been experienced in several operating systems. When chromate-based programs are used, chromate levels have been increased from 20 ppm up to 50 ppm to obtain satisfactory corrosion rates. Pitting is extremely important and can be used to determine the optimum levels of corrosion inhibitors to protect the heat exchangers.

Reduced, trivalent chromium is precipitated in the softener and removed within the sludge. Generally, less than 10 percent of the chromium is trivalent; however, should reducing conditions exist in the cooling water due to process leaks or atmospheric contamination, considerably higher levels can occur. Currently, trivalent chromium is considered to be much less toxic than the hexavalent form.

The balance of most chromate-based as well as nonchromate-based inhibitors are composed of zinc salts and phosphates; and less frequently, molybdates, silicates, and nitrates. The high pH of the softener effectively removes the zinc and phosphates. These materials must be replaced if they are used for protection of the heat exchangers. This is usually done by separate feed or with low chromate, high zinc and/or phosphate inhibitor formulations. Molybdates and nitrates are not removed by the high pH of the softener. Only silicates will be removed if the water has sufficient magnesium and the pH is above 10.5.

The only ingredient of standard corrosion inhibitor formulations that will adversely affect the softener is the presence of polyphosphates. They delay the softening reactions causing after precipitation and usually require higher dosages of hydroxide. Polyphosphate is removed in the softener as an insoluble calcium salt. Many chromate-based and some nonchromate-based corrosion inhibitors contain orthophosphate rather than polyphosphate. Orthophosphate does not appreciably interfere with the softener and is also precipitated and removed.

Microbiological Control

Microbiological control in a zero blowdown cooling water system requires application of toxicants continously and periodically to control levels of microorganisms. However, this type of system is essentially a closed cooling system that retains the contaminants and nutrients as well as the toxicants. Two main factors must be considered when selecting a microbiological program: (1) pH varies from the softener pH of about 11.0 down to the pH level of the cooling water, (2) chemicals added will cycle up within the system either as added, if they are stable under all the variable conditions, or as the degradation products. The high softener pH, it should be noted, will be toxic to microorganisms and augment the control program.

Oxidizing agents, such as chlorine, do not affect softener reactions nor the stability of the bed. They actually remove organics and can improve the precipitation reactions. The hypochlorite ion will pass through the softener if the chlorine demand of the calcium carbonate slurry is not too high. Chlorine is reduced to chloride ion and will be cycled up in the recirculating water. High chloride levels will increase the corrosivity of the water, thus requiring higher levels of corrosion inhibitor.

Other oxidizing biocides may be used instead of chlorine which will control microorganisms at higher pH and not contribute dissolved solids to the water. These include ozone and hydrogen peroxide. Chlorine is not very effective in recirculating waters of high operating pH, however, chlorine dioxide is effective and will not contribute as many chlorides.

Non-oxidizing agents often contain dispersants and are usually added as slug dosage. This can disrupt the softener sludge bed, resulting in carryover. Some nonoxidizing biocides are adsorbed by suspended solids or are destroyed by high pH, while others will pass through the softener to be recycled. It is important to be aware of the compatibility of some biocides with the deposit and corrosion inhibitors.

The sidestream softener system can be adversely affected by the cooling water chemicals as described. Conversely, the cooling water treatment may be adversely affected by the softener chemicals, particularly by polyelectrolytes which may be used as coagulant aids. These polyelectrolytes may be anionic, cationic, or nonionic. If their charge is opposite to the scale control or biocide treatments, one or both may be negated.

Monitoring

Monitoring the water treatment program is essential to maintain protection of the heat exchangers. This regular monitoring is for deposits, corrosion and biological accumulations.

Water Analysis. Daily and hourly testing is required to determine both the operating effectiveness of the softener and the treatment water control additives. Specific analyses and frequency should be established.

Deposit Monitor. In addition to watching heat transfer rates on actual equipment, a deposit monitor should be installed to continuously evaluate the control of scale and fouling deposits.

Corrosion Rate Monitor. Two types of monitors should be used: (1) corrosion coupons and (2) continous recording corrosion rate meters. Coupons of mild steel and copper alloys should be installed and removed on a 30-day frequency and evaluated for type and rate of corrosion. The use of a continous recording corrosion rate monitor, which can monitor several different probe types and locations continously, is very useful.

Microbiological Control. Concentractions of microorganisms in the cooling water should be analyzed and the results used to adjust the microbiocide dosages. Cooling water should be analyzed for both total bacteria counts and sulfate-reducing bacteria.

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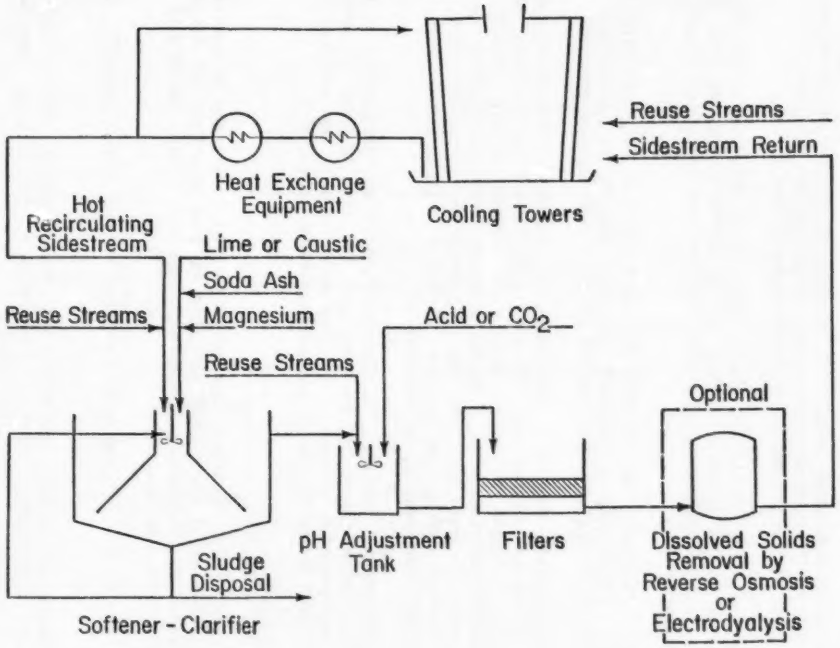
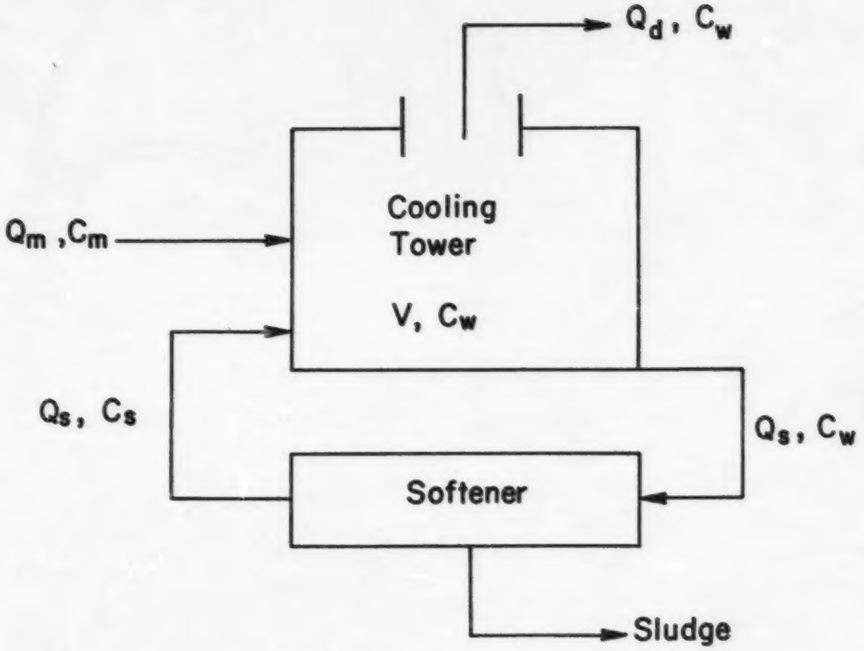
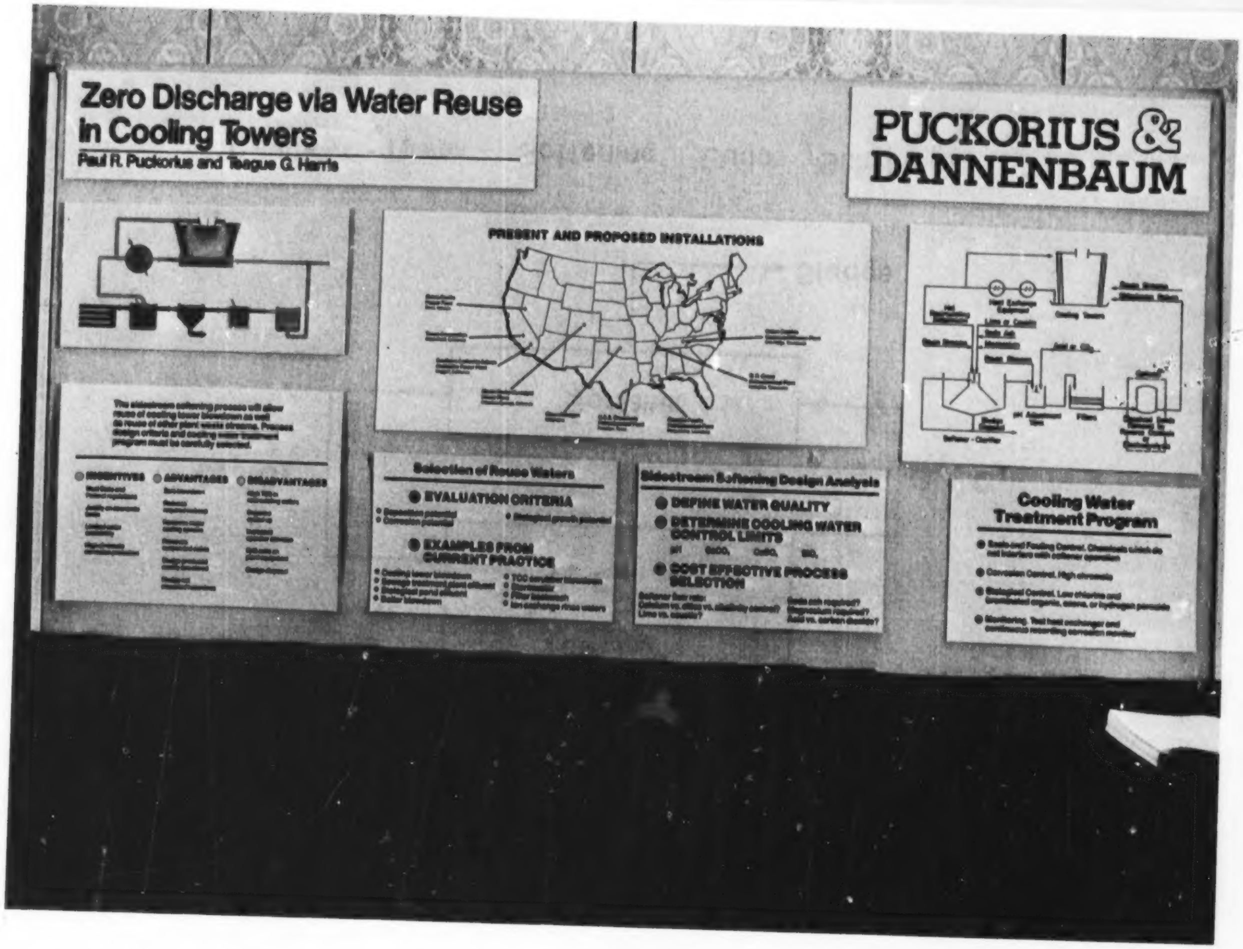

Reuse Streams
Sidestream Return
Heat Exchange Equipment
Cooling Towers
Hot Recirculating Sidestream
Lime or Caustic
Soda Ash
Reuse Streams
Magnesium
Acid or CO2
Reuse Streams
Optional
pH Adjustment Tank
Filters
Sludge Disposal
Dissolved Solids Removal by Reverse Osmosis or Electrodyalysis
Softener - Clarifier

FIGURE 1


Q_d, C_w
Cooling Tower
V, C_w
Q_m, C_m
Q_s, C_s
Q_s, C_w
Softener
Sludge

Cooling Tower Softening Loop Schematic

FIGURE 2


Zero Discharge via Water Reuse in Cooling Towers
Paul R. Puckorius and Teague G. Harris
PUCKORIUS & DANNENBAUM
PRESENT AND PROPOSED INSTALLATIONS
INCENTIVES
ADVANTAGES
DISADVANTAGES
Selection of Reuse Waters
EVALUATION CRITERIA
EXAMPLES FROM CURRENT PRACTICE
Sidestream Softening Design Analysis
DEFINE WATER QUALITY
DETERMINE COOLING WATER CONTROL LIMITS
COST EFFECTIVE PROCESS SELECTION
Cooling Water Treatment Program

PB82-223629

THE USE OF WASTE HEAT FROM INDUSTRIAL NON-CONTACT COOLING WATER FOR COMFORT HEATING

Harry I. Leon, Ph.D., P.E.
President
Leon & Associates, Consulting Engrs.
924 Bowen St., N.W.
Atlanta, Georgia 30318

INTRODUCTION

A large number of manufacturers utilize potable water for cooling machinery. It has been common practice to pass the water once through the machinery and then to discharge it either to an outfall system or to a sewer. In this fashion, tremendous quantities of essentially clean water as well as substantial amounts of low grade thermal energy in the form of warm water are lost. This waste heat, if recovered, can be utilized to reduce many a factory's reliance on other forms of energy for comfort heating.

Moreover, a sharp reduction in water consumption as well as the availability of low grade thermal energy for comfort heating are not the only benefits realizable by the reuse of non-contact cooling water. Enhanced protection of factory machinery from corrosion, overheating, and thermal shock is also obtainable. These several benefits have been demonstrated in systems which the author designed, as a consulting engineer, for the 150,000 sq. ft. plant of Chambers Corporation, located in Oxford, Mississippi. These and other water-recycling systems (1) which the author engineered for Chambers Corporation are operated in conjunction with processes which transform sheet steel from virgin material to the painted or porcelain-enameled parts of large kitchen appliances.

Wastewater Sources

Early in the design of an industrial wastewater treatment system for the Chambers' facility, it was found that the flow of non-contact cooling water amounted to nearly 60% of the total wastewater discharge. This portion of the flow was potable water which had been passed once through machinery and then had been discharged to the outfall system. The non-contact cooling waters by themselves were of sufficient purity that the state regulatory agency, the Mississippi Air and Water Pollution Control Commission, would have allowed them to be discharged directly to the outfall system without any treatment, provided they were segregated from the remainder of the wastewater flow.

By merely separating the non-contact cooling water from the process discharge water, significant savings in the capital cost of the treatment facility could have been achieved. But Chambers Corporation was already consuming about 10% of the City of Oxford's total daily water flow; and the water table in Oxford was falling at the rate of one foot per year. Chambers' management, foreseeing increased water consumption requirements for their plant, elected to invest the additional funds required to recycle the non-contact cooling water.

Growth in Coolant Water Demand

The anticipated reduction of water charges was estimated in 1975 to be adequate to pay for the capital and installation costs of the non-contact cooling water recycling system in about 2½ years. As it turned out, the total installed cost of this system has amounted to only $21,300.00, a sum which, with the recent expansion of the plant and of machinery requiring coolant water, has been recovered in a ten month period. During this expansion, the coolant water requirements increased from a continuous flow of 40 gpm (2.5 liters/sec.) to a continuous flow of 115 gpm (7.3 liters/sec.) with a maximum flow rate of 200 gpm (13 liters/sec.). Chambers' growth would have been handicapped without the water recycling system because the City of Oxford was having difficulty in finding wells to meet any increased water demand and had requested that Chambers find ways to conserve water.

Differences in Coolant Water Requirements

Coolant waters in the Chambers' plant were required for the operation of spot and seam welders, the condenser of the office area air conditioner, and two 100 hp air compressors used to produce the plant compressed air supply. The first step in designing the non-contact cooling water recycling system was to determine: (1) the required inlet conditions (including flow rate and water temperature) for the various machines, (2) the pressure drop across each, and (3) the heat load contributed by each. Significant differences existed. The spot and seam welders taken as a group required a high flow rate at a relatively low inlet temperature (85°F (29°C) maximum); the pressure drop across these machines was high (50 psi (3.5 kg/cm^2)). The condenser for the air conditioner, on the other hand, though requiring a coolant flow meeting inlet conditions similar to those of the spot and seam welders, nevertheless, contributed a heat load which was much greater than the composite spot/seam welder group. The 100 hp air compressors were another variation: they required a higher inlet water temperature to prevent condensation from forming within than did the other machines. Moreover, the pressure drop across the cooling jackets of the air compressors was much lower (only about 10 psi (0.7 kg/cm^2)). Additionally, there was a higher temperature rise in the water passing through the air compressors than through the spot welders.

Because of these differences, the author decided that from a reliability standpoint it would be best to design two separate recycling systems. Accordingly, two systems were developed: one to conserve the water utilized in cooling the air compressors and the other to conserve the cooling waters for the spot and seam welder machines and for the air conditioner condenser.

A separate system was not designed for recycling the air conditioner condenser coolant water because this unit was compatible with the inlet water conditions of the spot and seam welders. In addition, the flow rate through the air conditioner condenser amounted to only 10% of the total flow capacity of the combined spot and seam welders/air conditioner group, allowing the higher heat load of the air conditioner condenser to be easily dissipated. A further consideration was the fact that the air conditioner was used only part of the year.

In addition to increasing reliability, the use of separate recycling systems allowed for an increased flexibility in factory operation and provided for a minimum of plant disruption in the event of component failure.

DESIGN OF THE SPOT WELDER COOLANT RECYCLING SYSTEM

The system for recycling the non-contact cooling water to the spot and seam welders and to the air conditioner condenser is a closed one, with the water cooled and then returned to the machines. The waste heat from the machines is used to heat the factory in the winter time. This system, shown schematically in Figure 1, consists basically of a distribution network for both supply and return water, a 10 hp centrifugal pump, two water-to-air heat exchangers (one of which is evaporatively cooled), and controls. The coolant waters, once they pass through the machines, collect on the return side of the system and then flow to the pump, from which water is circulated to one of the two heat exchangers and back to the machines.

The system was designed to maintain an 85°F (29°C) or less inlet water temperature and a sufficient flow rate to each component requiring coolant so that none would become starved for water and overheated. The flow requirements for the various machines exhibited a wide variation from 0.5 gpm (0.03 liters/sec.) to 70 gpm (4.4 liters/sec.). In order to maintain an adequate flow to each individual machine, the network for both supply and return was designed in a looping grid work of parallel piping. This piping was sized so that the pressure loss in the distribution system is less than 10% of the pressure drop in the overall system. The bulk of the pressure drop was in the spot and seam welder machines themselves. The low pressure drop in the distribution network allowed for ease of regulation of the flow to each component spot welder. This looping type of flow pattern also eliminated dead spots and reduced the possibilities of scale buildup in the system.

In order to maintain the 85°F (29°C) or less water inlet condition, the system was equipped with two heat exchangers, one a closed-circuit, evaporative cooler unit which is located on the factory roof, and the other a water-to-air fan coil unit which is located in the factory and suspended from its ceiling. A 10 hp centrifugal pump, which was found adequate for this recycling system, is located near the fan coil unit.

The heat exchangers were sized so that each, by itself, could discharge the heat gained in cooling the spot and seam welder equipment. The inside heat exchanger was suspended from the ceiling of the factory so that the heat discharged from it could be used to help warm the spot welder operators in the winter time. The second heat exchanger, the evaporative water cooler unit located on the roof, was sized somewhat larger than the inside heat exchanger. A larger outside unit was required to facilitate the discharge of the additional heat gained in cooling the condenser of the air conditioner.

Automatic controls select either the inside or the outside heat exchanger to cool the non-contact cooling water. This selection is dependent upon the difference between the desired and actual ambient temperatures of the factory; a thermostat (T_2 in Figure 1) is set for the desired temperature of the factory. If the ambient temperature of the factory is cooler than this set temperature (approximately 70°F (21°C)), the inside unit is called upon to perform the cooling function and at the same time to add the heat removed from the water to the factory for comfort heating. If the factory is above the set temperature, the outside unit is called upon.

These controls do not allow either the inside or outside heat exchanger fan to be turned on until it is required. A thermostat (T_1 in Figure 1) activates each of these fans. If the water temperature is below 70°F, the water proceeds around the loop until the temperature reaches 70°F (21°C). This procedure prevents cold drafts of air from being discharged through the factory in the winter time and the waste of electrical energy in running the fans unnecessarily. On a year-around basis, the latter saving decreases the operating costs by 50%.

Controls for the Protection of the Machines

The design also provides for control devices on each machine which automatically turn it off when the flow to it is inadequate. Such devices are shown schematically in Figure 1 for a typical spot welder.

A second major failure condition which may occur is an elevated inlet water temperature. The system was designed to maintain a temperature below 85°F (29°C) in the water entering the machines, as mentioned above. However, in the northern Mississippi area in which the system is located, wet bulb temperatures exceed 85°F (29°C) 2% of the time;(2) and therefore an auxiliary system (also shown schematically in Figure 1) is occasionally required. This system automatically goes into operation when the inlet water temperatures cannot be maintained below 85°F (29°C).

This backup system consists basically of a thermostatically-controlled solenoid valve (V_3 in Figure 1) that allows water hotter than 85°F (29°C) in the return system to be sprayed onto the factory roof while city water at ground water temperature enters the system for makeup. If in fact the water in the return system rises to 85°F (29°C), this occurence would be sensed by a thermostat (T_3 in Figure 1) which is located downstream of the heat exchangers. The roof spray feature was selected so that some cooling of the factory building is achieved as the water escapes the system. The water, because of its relative purity, is allowed to leave the building area through storm sewer drains and is not collected for treatment with other factory discharges.

For added protection, a red light on the control panel goes on when the water temperature at the thermostat T_3 reaches 85°F (29°C). In addition, an alarm is sounded if the water temperature continues to rise to 90°F (32°C). This same bell also indicates the loss of flow in the system. A temperature of 90°F (32°C) in the water of the system is indicative of the failure of the roof spray system or of a pump failure. In either case, the operator needs only to open two manual valves; and the system reverts to a once-through cooling system with discharge to the roof.

For winter operations, a thermostatically-controlled solenoid valve (V_4 in Figure 1) automatically drains the external piping when two conditions are met: the outside temperature falls below 40°F (4°C) and the outside unit is not required. For severe freezes, experience has shown that it is necessary to add antifreeze to protect the tubing of the outside heat exchanger, which still retains water in the amount of about 20% of its water-holding capacity even when drained. Manual valves are provided so that the outside heat exchanger unit can be isolated from the remainder of the system prior to filling this unit with an antifreeze solution.

DESIGN OF THE AIR COMPRESSOR COOLANT RECYCLING SYSTEM

The recycling system for the non-contact cooling water for the air compressors is very similar to the system for the spot/seam welders and the air conditioner condenser. The system was designed to cool two 100 hp air compressors each generating about 180,000 BTU/hour (45,000 kcal/hour) of waste heat.

The system consists basically of two water-to-air heat exchanger units and a 5 hp centrifugal pump. The pump circulates water to the cooling jackets of the air compressors on the outlet of which a self-contained temperature valve regulates the flow rate so as to maintain a desired outlet water temperature of approximately 100°F (38°C).

Water is pumped to either the inside or the outside heat exchanger; controls similar to those for the spot/seam welder coolant recycling system direct the flow. Due to the higher temperature rise in the coolant flow across the air compressors, a thermostat performing the function of the thermostat T_1 in Figure 1 is not required.

If the temperature of the air compressor coolant water discharge is increased beyond 140°F (60°C), a separate control will automatically turn off the air compressors. A thermostatically-controlled solenoid valve allows the return water to be sprayed onto the roof whenever the temperature of the supply water is greater than 90°F (32°C).

The freeze protection for the air compressors coolant water recycling system is similar to that provided in the system for the spot/seam welders and air conditioner condenser.

OPERATING EXPERIENCE WITH SYSTEMS

From a maintenance point-of-view, corrosion of the piping has been reduced because of the lower oxygen content of the recycled water as compared to that of fresh water. In the systems described in this paper, very little corrosion has been noted in four years of operation.

There are also other reasons why greater protection for machines requiring coolant water is provided by the water recycling systems than would be the case for a once-through system; specifically:

(1) a closed system is virtually immune to fluctuations in the municipal water supply quantity or pressure; thus substantial heat capacity is effectively built into the system, reducing the likelihood of overheating; and

(2) a more uniform temperature can be maintained throughout the year resulting in a more stable performance; in winter, the water is circulated around the loop several times until its temperature reaches 70°F (21°C) instead of shocking the machines with 50°F (10°F) winter ground water temperature; in summer, the water in the system is maintained at approximately 78°F (26°C).

COMFORT HEATING UTILIZING WASTE HEAT

The factory workers noted no change in the operation of the spot and seam welders but did appreciate the extra comfort heating provided by the two systems in the winter. The low grade thermal energy recovered with these systems was found capable of raising the factory temperature approximately 10°F (6°C). At today's natural gas prices, the concomitant savings amounted to about $1500.00 per year.

MAINTENANCE AND OPERATING COSTS

At the present time, the spot and seam welder recycling system is costing about $5.00 per day to operate and saving about $170.00 per day in water charges. Electrical energy consumption is kept to a minimum by running the heat exchanger fans only as required.

The electricity needed to run the heat exchanger fans is minimal, with the fan of the inside unit (having a 5 hp motor) on only one-third of the time in winter, and the fan of the outside unit on only about one-half time in spring.

Operator time is also kept to a minimum. The operator needs only to turn on a switch in the morning and check the pressure, flow, and temperature gauges about twice a day in order to insure proper function of each system.

CONCLUSIONS

This paper shows that there is no need for industries to discharge non-contact cooling water. The equipment for recycling the water is currently available and very reliable. Systems, such as the ones discussed here, can be designed which have very low operating costs and require minimal operator attention.

Further, water recycling systems are an improvement over once-through systems from the point-of-view of protecting factory machinery from overheating, from thermal shock, and from corrosion.

Water recycling systems are more economical than their once-through counterparts: the savings from reduced water and fuel consumption can pay for the capital costs of the installed equipment in the former systems in less than one year's time.

Last, but not least, the declining water tables across the United States make it a national interest that industries utilize every opportunity to conserve this valuable resource.

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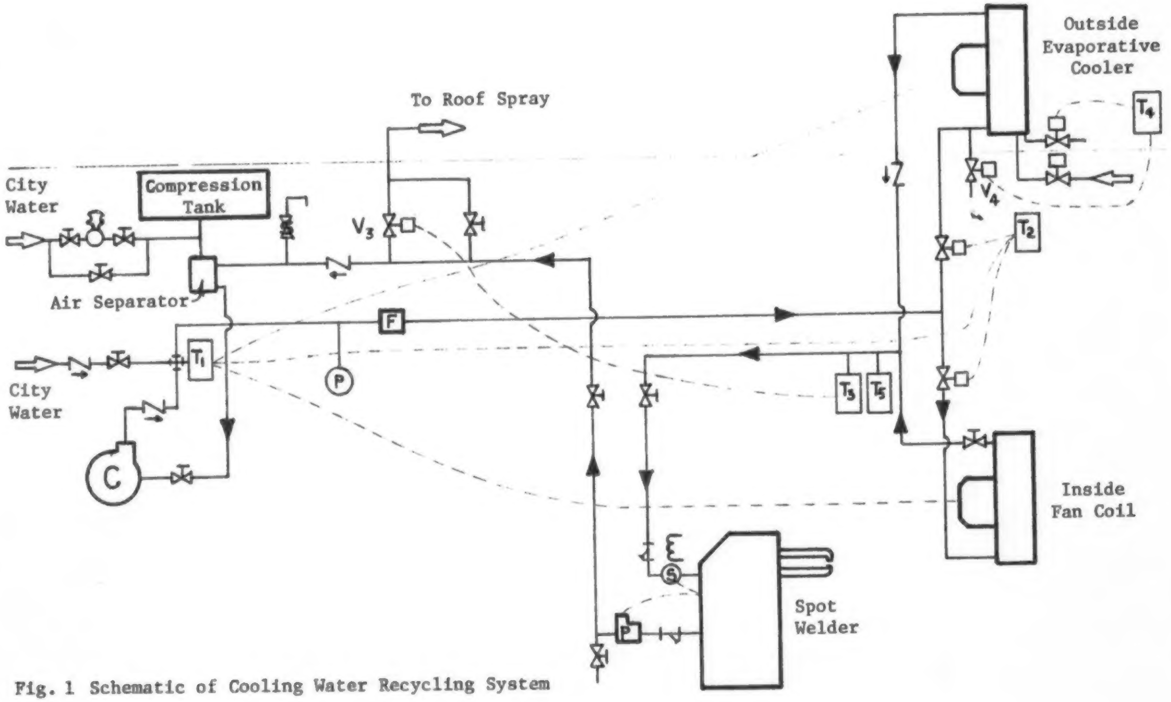
Outside
Evaporative
Cooler
To Roof Spray
T_4
City
Water
Compression
Tank
V_3
V_4
T_2
Air Separator
F
T_1
P
City
Water
C
T_3
T_5
Inside
Fan Coil
S
P
Spot
Welder

Fig. 1 Schematic of Cooling Water Recycling System